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Plate I.

THE ZODIACAL LIGHT. *(see P. 223.)*

"a" Meteor of 1861. *(Webb)*

(Frontispiece.)

Vincent Brooks Day & Son, lith.

ASTRONOMY

SIMPLIFIED FOR GENERAL READING,

WITH

Numerous New Explanations and Discoveries

IN

SPECTRUM ANALYSIS,

ETC., ETC.

BY

J. A. S. ROLLWYN.

> "OF OLD HAST THOU LAID THE FOUNDATION OF THE EARTH:
> AND THE HEAVENS ARE THE WORK OF THY HANDS.
> THEY SHALL PERISH, BUT THOU SHALT ENDURE;
> YEA, ALL OF THEM SHALL WAX OLD LIKE A GARMENT:
> AS A VESTURE SHALT THOU CHANGE THEM, AND THEY SHALL BE CHANGED.
> BUT THOU ART THE SAME, AND THE LIGHT OF THY YEARS SHALL NOT FAIL."

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1875.

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PREFACE.

SOME reasons may be asked for the appearance of the present volume. The author hopes its distinctiveness will form its best justification. But of the motives which induced its production, he may also be permitted to explain that while many things go forth to the general world, apparently under the authority of Science, which are only after all matter of speculation without any scientific sanction—for science can never be said in itself to sanction that which it has not absolutely ascertained—the public mind is, as a rule, not sufficiently acquainted with the rationalia involved to be capable of self-protection, or to be able to distinguish, as scientific men themselves generally do, what has been definitively discovered from what has, in the absence of discovery, been plausibly suggested. The rationalia of the science, therefore, in such terms as the general intelligence of the non-scientific may readily appreciate, appeared a desirable addition to untechnical though strictly scientific literature; and the more so, as it is not from want of high and accurate reasoning powers that general readers are deterred from the practical study and investigation of even the most abstruse scientific subjects, but from the technical obstructions to their patience and perseverance which they have to encounter at the outset.

The day has passed when the attainments of knowledge and intellect are matters of indifference to the general public. They are now rather objects of universal emulation; and, to clear the path for repelled intelligence—to show to general thinkers who are deeply interested, even while they stand aloof from the strictly scientific aspects of the subject, where they may check the vagaries of the merely speculative, and, it may be, also tempt them at last, by simplification of method, to take a part in the advancement of truth itself, can be no mean or unjustifiable aim, however humble the work. On the other hand, while much has been recently done to popularize science, and astronomical science in particular, there is a certain method which the present writer cannot help thinking has been greatly neglected, namely, the influence of comparison, with reference to each difficult or isolated fact, as a means of localizing and throwing broad light upon what, when stated alone, would scarcely be intelligible, and, from want of associated interest, would soon be forgotten.

Thus it may be said that we cannot form any idea of the enormous stretch implied in a length of 426,000,000,000,000 miles, the distance of the bright star Capella from our world; and this is strictly true; but so dependent is the mind of man upon adequate means to each particular conclusion it makes, that we have just the same difficulty in forming, without such aid, an accurate idea of the distance of twenty yards; for few men would guarantee that the length of a particular line was precisely twenty yards, without taking means to make sure of the fact by the aid of reliable standards of measurement. And if the standard lineal yard were destroyed, and all the standards of measurement dependent upon or employed in the production of it, it is doubtful whether we would ever in the whole future history of man be able to erect the same precise unit of measurement again. At any rate, we never would be able to rely on our having done so, although any other unit of measurement would serve all practical purposes equally well. Now, as no man carries the standard unit of measure in his eye, we can form mentally just as accurate an idea of a line 426,000,000,000,000 miles long, as of a line twenty yards long; that is, our mental impression of neither will be very precise, save that both are lines of different but limited extent; and perhaps the great majority of us have neither occasion nor intention to measure precisely the one line or the other for ourselves in the whole course of our lives; nor would we be much better for doing so, as matter of mere subsequent mental reliance, without recurring to the standard measure again and again, as occasion and accuracy required. We will, in ordinary cases, be content, possibly enough, with such associate standards of comparison as we can readily find, if there be any at our command, and will assume the sufficiency of the standard, just as the framers of our existing unit of measurement had to assume the right to call a certain length of line by the term a yard, and make it the basis practically of measuring other and longer lines. When we say that Capella is 4,484,000 times further distant from us than the sun, we reduce the idea of 426,000,000,000,000 to much more comprehensible dimensions; and when we say further that Capella is only about 150,000 times further from us than the newly discovered planet Neptune is distant from the Sun, we have reduced the numbers of our standard of comparison to something considerably fewer than the pounds sterling in which we are accustomed to set forth and know precisely the amount of the National debt of Great Britain, which, if stated in pence, would be quite as incomprehensible as the distance of Capella in miles. When we add that Sirius, the brightest of the fixed stars, is only 45,000 times further, and α Centauri, the nearest of the fixed stars, only 7,500 times further from us than Neptune is from the Sun; and that solar attraction—as shown by the visitations of periodical comets in traversing their extremely elongated orbits in connection with our system—extends to probably one-fourth of this latter distance to α Centauri, we come at last to a set of associated facts, which furnish the mind with as accurate ideas as we have of the extent of British commerce, or the annual transactions of the Bank of England. Other kinds of comparison will be found also to aid us considerably in the realizing of other series of facts, and give picturesqueness and interest to what would be otherwise mere barren and uninviting detail.

It was not in contemplation at the outset of the work to deal so fully with SPECTRUM ANALYSIS as has been done in the chapters specially devoted to that subject. But the facts grew so much by study and experiment on the author's hands under the light of previous and independent investigations, that it would have been unfair to the preceding context to have gone less fully into the results arrived at; notwithstanding the large amount of the subject which has, for reasons explained in their proper place, been in the meanwhile withheld.

For the introduction of the concluding chapter of the work in such a place, possibly some special explanation may seem to be required; but really, as will appear from the statement given in the treatment of that subject, those mathematicians are most to blame who, having themselves encountered a supreme scientific difficulty, have, by hasty assertions of *impossibility*, created unwarrantable obstructions in the path of effort and discovery, and made it, after the difficulty was so far conquered, almost as impossible to obtain for it due attention and recognition, and its rightful place in scientific truth and achievement, as it has so long been to find the solution of the problem itself. Such a course is certainly not the most likely to encourage or promote the advancement of science—it is, in fact, by a foregone conclusion, fixing a brand upon the man who attempts it; and yet the problem has engaged the attention and effort of some of the noblest thinkers among mankind.

LONDON, *Dec.* 1870.

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PART I.

FUNDAMENTAL TRUTHS.

CHAPTER I.

The Three Primary Truths of Astronomy: Infinitude, Eternity, Omnipotence—Impossibility of Accident—Irregularity—Result of it not accident or imperfection, but new discovery of adequate causes—Infallibility of Power—Pantheism—The Principle of Self-existence—Its Residence, not in Matter or Nature, but in Power.

On the threshold of this Imperial Science we penetrate the peculiar domain of three grand truths, the most sublime by which the soul of man can be overawed or his intelligence awakened. We are under, what is to us, the vestibule of illimitable space, stretching outward in every direction around us, filled with illimitable and interminable action, controlled by illimitable power. We have the evidence and the operations of INFINITUDE—ETERNITY—OMNIPOTENCE, consciously to contemplate, irresistibly to perceive. For incomprehensible as these three ideas are in themselves to the unaided capacity of mankind, they are presented with such absolute certainty to the student of astronomy, that evasion of their truth and reality is impossible. We may not understand anything of infinitude; but that is just because the limitation of astronomical space at any point or in any direction is utterly inconceivable. We may not understand anything of eternity, just because an absolute period to the universe is beyond all the power of our natural conception. We may in like manner know nothing of Omnipotence; but just because a limit to the power which has set these myriads of unexplored and interminable systems in motion, which the telescope of the astronomer enables him dimly to descry in the vanishing or dawning depths of ever-increasing distance, is as incomprehensible as the limits of that range or space within which it operates, or the varied yet ever-concurring harmonies it controls. But these difficulties, arising from our own infirmity and the limits of our position, imply no uncertainty or unconsciousness of the existence of the truths themselves, though we cannot fully understand them, any more than our ignorance of the termini of a strange path on which we may have strayed makes us uncertain or unconscious of the existence of the path itself on which we have actually placed our feet. It is but the limit that we cannot understand—the thing that to these three great truths *is not*—because we cannot form a limited definition of realities whose definition by limitation is impossible. Are men absolutely unacquainted with subjects as incapable of definition, though of a more familiar class? The philosopher must have insisted on very absolute conditions, at variance with all his most familiar experience, who maintained that everything must have form, size, and colour. What is the form, size, or colour of human thought, of human feeling, of human life, of time, of avarice, of hate, of patience? Yet who doubts or denies the existence of all these because their distinctiveness is not a matter of definition, save by their own separately perceived and respective identities?

So neither in the presence of astronomical science can we deny the existence of Omnipotence, Eternity, and Infinitude. Had infinitude existed without Omnipotence, eternity would have co-existed with infinitude. But the power which can traverse both, and visibly fill them with motion and variety, and arrangement and change, must be as infinite as the range within which it operates and the variety and change it achieves, and the limits of which we can neither determine nor explore. Men are naturally awed by the consciousness that they must be under the absolute control of such a power, and are impressed with a sense of fear and of danger, and they are often, therefore, apt to exclude the consciousness altogether—its absence from their thoughts being necessary to their present comfort; but astronomy, in displaying the grander working of that power, in contemplating the everlasting strength with which sphere is balanced with sphere, and the empyreal frontiers by which system is separated from system, becomes a means of making man conscious of the security he enjoys and the Almighty protection of which he partakes; and by its study he feels the more deeply convinced that his safety is not the result of accident, or neglect, or indifference, but is part of an enforced and ordered and beautifully consistent and beneficent purpose, in which provision is made for the minutest want, as well as against the mightiest and most disastrous danger—in which accident and confusion are excluded, and derangement and failure impossible. Little as we know of infinitude and eternity, still less do we know, or are we able to conceive, of that sublime and impersonated Power which reigns supreme and absolute in, throughout, and over both; which can simultaneously perceive all the spaces which the great star systems require, and make order and arrangement ample enough for each, and balance and combine forces which would otherwise jar and conflict, and set the most stupendous, as well as the most minute influences in operation, and at the same time be in itself invisibly veiled in sacred and impenetrable majesty from each, yet consciously Omnipresent and Omnipotent over all.

True, the mind of man will still recur to the question—May not such a thing as accident occur in all this? Let us propose, in reply, the previous question. If everything in space were still and at perfect rest, how could accident under such circumstances occur? With all things in a state of perfect rest, accident or conflict among them is impossible. But may there not be such a thing as accidental motion? No doubt man is privileged to put such a question; but who may confidently answer it in the affirmative? He who would do so has another question to answer first—By what means could accident produce motion? Motion is the evidence and result, not of accident, but of power. As an axiomatic fact, *Motion is Power;* but accident is not power. Accident cannot, therefore, originate motion; but what we are accustomed to call accident is a result of power already in motion, and not an originator of motion or of power. Accident, so called, therefore, is inferior and subordinate to power. In truth, as has been demonstrated otherwise, there is no such thing as accident, and what we call so is only the inevitable and logical result of power acting under certain conditions. The shocking and horrifying incident at Abergele, for example, was not an accident, but an infallible result of the circumstances under which it occurred. Under all the circumstances, just as they were, it could not have resulted otherwise. We must import a new element into the circumstances before we can conceive of another result. It was not accident, consequently, but a certain and infallible consequence of the circumstances; and the only thing which relieves it of the enormous wickedness of design is, that those who might have prevented it did not exercise the forethought necessary to enable them to perceive the imminent and inevitable nearness of the result, and did not, therefore, incur the guilt of deliberately purposing and allowing it. And so it is of all power exerted: all its results are inevitable consequences of it under their respective circumstances, and the being who sets a power in motion without foreseeing all the consequences is not entirely free from responsibility for these consequences simply because they are unforeseen. He is bound, so long as it is under his control, to regulate and restrain the power within the limits of safety, and he is never justified in setting it free from control, save where he is *perfectly certain that injury cannot possibly result.*

Now this is precisely what we maintain of the Great Power which has set the mighty star systems and forces of infinitude in motion. We maintain, by parity of reasoning, that these motions are not the result of accident, but the evidence of immense and illimitable power, of an Omnipotence everywhere omnipresent, and demonstrated by the combined harmony and co-operation of the whole; that every result of these motions is inevitable, perceived, forecontemplated, and purposed; and that accident is here also absolutely excluded. We have here system after system stretching outward, as widely and immeasurably apart as the telescope with its highest powers can enable us to penetrate, in every direction, and nowhere disorder or confusion pervading or prevailing against the mighty whole. Under such circumstances we must conclude that the power which regulates the great result, and achieves its stability and harmony from remotest to remotest space in every direction, must be great enough to compass all inferior consequences, and that what we would call accident in any part must be fore-contemplated purpose, as certainly as we have shown that it must be inevitable result. The spheres of heaven are so finely balanced that we never dream of looking at them as casual and precarious combinations or factitious arrangements, but we recognise them as fettered by laws, weighed and poised together by exactly-adjusted and perfectly-meted influences and forces, so that we estimate them by the most complex calculations, which surprise and delight us by their accuracy, and enable us to adopt and rely on them as the most certain and trustworthy bases of all that we hold most exact in weight or just in measure among ourselves, in discharging with integrity the commercial business and moral responsibility of our lives. Nay, a perturbation in the system, where such a thing occurs, inevitably leads to a new and astonishing discovery, which we might never have otherwise made. By means of it, instead of the accuracy of the system being rendered doubtful, we have been enabled to add, during the last few years, the discovery of two new planets—NEPTUNE and VULCAN—to the solar system; and by the same means we have corrected our miscalculations, and come nearer to an accurate knowledge of the weight and density of distant planets and satellites; and have, therefore, by a double proof, shown that such a thing as even the slightest irregularity cannot exist without an adequate, perfectly harmonious, and exactly-adjusted cause.

We find thus that unfailing and infallible accuracy are the characteristics of the Great Power by which the heavenly bodies are balanced and controlled, and that this is everywhere demonstrated in the operations and their results. True, it is difficult to conceive anything of the personality of that Power, but the reality of it is a fact impossible to evade. A first Cause is manifest and intrinsic to what we know, and we much suspect that where men hesitate to ascribe the quality of inherent self-existence to DEITY it is the very consciousness of the necessity for self-existence in a great primary cause somewhere that makes them, as pantheists, insist on ascribing it to NATURE and MATTER, even where the dependence of matter and its abject subjection to the law and circumstance of Power so plainly demonstrate that their proposition cannot be logically sustained. May we not ask, What is the objection of the pantheist, on a dialectic basis, to ascribing to Power that which he does not hesitate to ascribe to Matter or Nature? If the pantheist admits the principle of self-existence at all, and yet knows and feels that it is not in himself nor in the matter of which he is composed, so far as his particular identity is concerned, what is the objection to ascribing it to the Power by which his various elements are, for the time being, combined into that association which constitutes and sustains him? Power we perceive to be the absolute master of everything—nowhere do we find it absent. It is Ubiquitous, Absolute, Omnipresent, Omnipotent. On what logical basis can we deny it to be Self-existent? By what parity of reasoning can we assert that Nature is self-existent, and that its master, Power, is not? Can the pantheist give reasons for denying that Power is self-existent? But this would be asking him to prove and establish the negative. True, it has that aspect; but just so long as it is in this dim-lit world the privilege of every self-willed objector, who asks a reason in every case himself, and renders none in any, to deny more in an hour than a hundred philosophers can prove in a hundred years, so long is it legitimate to hold that negatives, merely, no more justify infidelity than they break down or build up truths.

It is quite certain that the pantheist admits the *principle* of self-existence, and feels conscious of the necessity for it at the root of all things somewhere. His blunder is in misplacing it. He has no right to ascribe it to the subjective, and deny it to the dominant. And clearly and demonstrably to all our experience, Nature and Matter are the subjective, and Power is the dominant. By every law of logic, therefore, by every inherent attribute of truth, the dominant must be the self-existent; and the subjective must be merely the contingent and dependent.

Power, then, is self-existent, and is the dominant of all things. It pervades infinitude. It prolongs and perpetuates time. It effects action. It accomplishes change. It perfects arrangement. It cancels, varies, and reconstructs. By its self-sustaining energy it expands Eternity into all its interminable attributes. It is Omnipresent, Omnipotent. Its Omniscience is co-extensive with its Infinite action, therefore its Knowledge is perfect, and its Wisdom complete. It is Maker, Master, Lord of all. No one who studies astronomy, ever so slightly, can fail to perceive from it that the highest of all the manifestations of Power is full of Intelligence and Skill. The heavens, of all created witnesses, draw nearest to their Creator's throne, and, as they range themselves before it, declare, with a surrounding and overwhelming testimony which drowns all infidelity, and hems in all atheism within the narrow boundary of its own benighted ignorance, their full and intense corroboration of that utterance of the inspired psalmist—"Power belongeth unto God!"* Let us be satisfied that it is so. It would be no gain to us were it otherwise. It is the highest guarantee of all our noblest hopes; for to the same supreme source belong also redemption and the issues from death.

But we will now proceed with the special purpose of our work, and leave the proclamation and praise of the Omnipotent to those mightier and purer, those celestial worshippers. It is fit that man should be but a listener, while the grand choir of infinitude swells forth that mighty pæan—while the heavens declare the glory of God, and demonstrate that almighty handiwork, which they are so perfectly qualified to testify and so specially deputed to display. The voice of man would be but a feeble utterance where the echoes of Eternity ring and reverberate with the rapturous hallelujahs of all the exulting Stars.

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* Psalm lxii. 11.

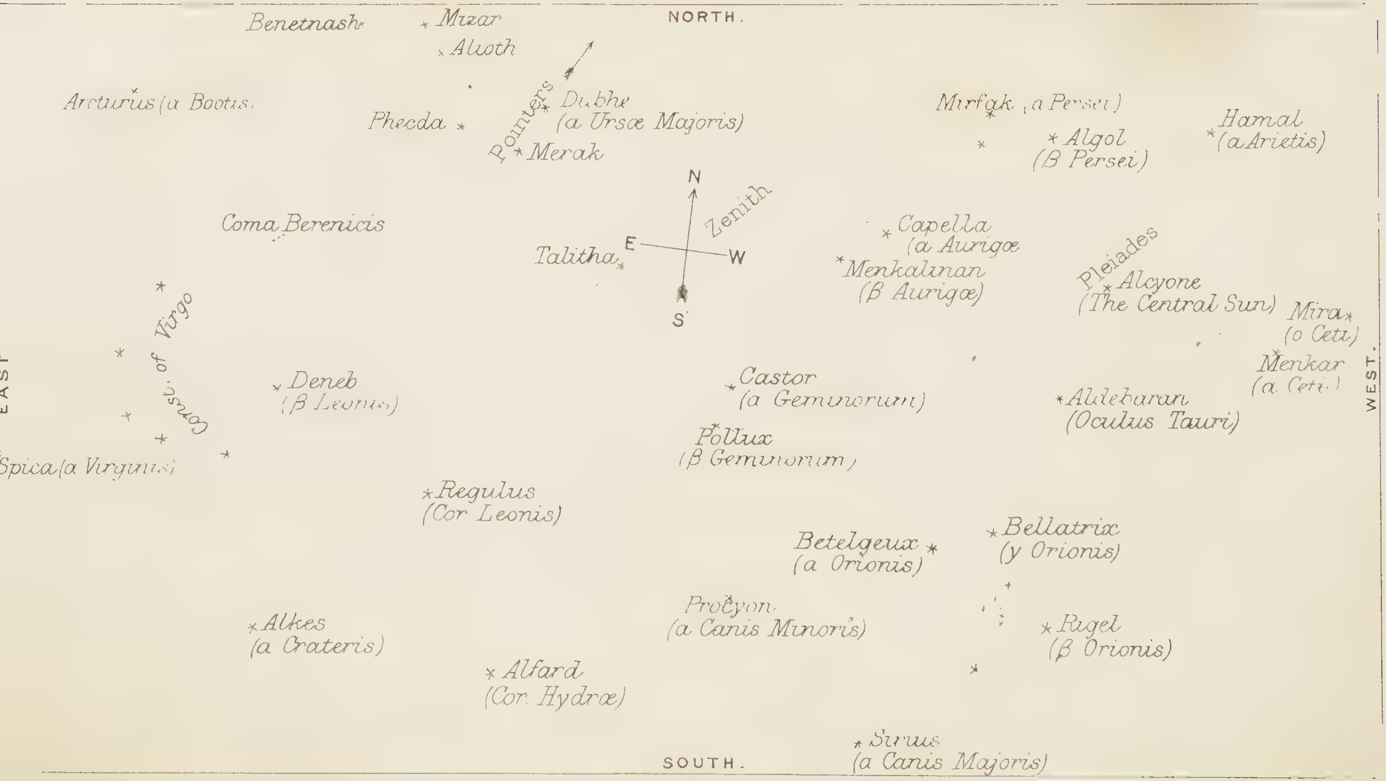
CHAPTER II.

Distance of the Stars—Star System of Sirius—Bodies of the Stars Invisible—Star Rays cannot give a focal image—Approximate size of Sirius and his companion—Areas of Attraction of the Nearer Stars—Star Systems around us, and the space they occupy between us and the Nebulæ—Multiple Star Systems—The Septuple Star System in Orion (Theta Orionis)—Orbits and period of the Star Systems.

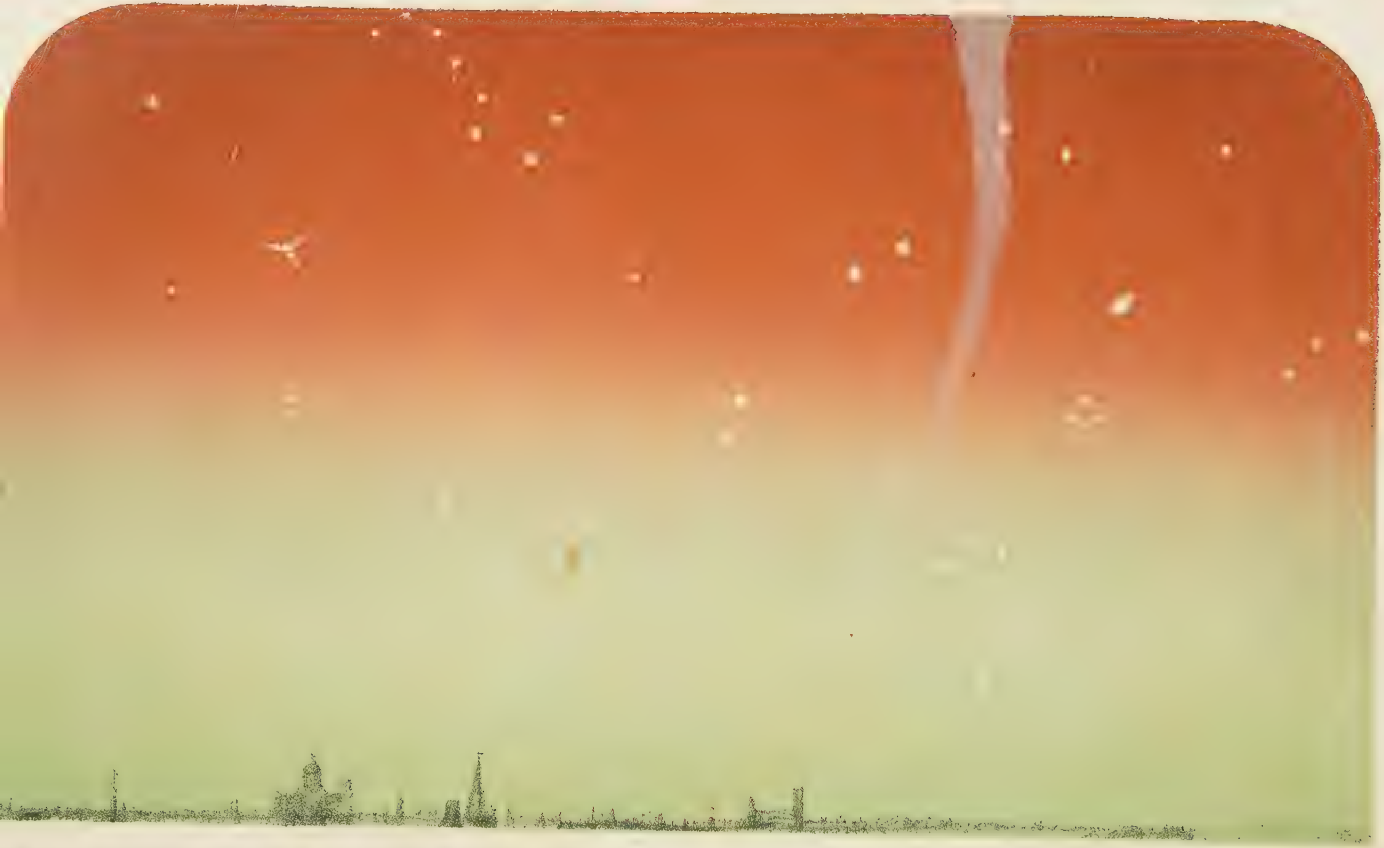
External to our own solar system, the nearest of all the fixed stars to us has been ascertained to be *a* Centauri, a bright star about thirty degrees northward from the south celestial pole, and very near to the celebrated Southern Cross. It is consequently not visible from our latitude. Its distance is about 21,508,000,000,000 miles, or about 226,400 times further from us than our own sun. Of course astronomical facts can only be estimated by astronomical standards, and require to be regarded, therefore, relatively to each other. The recently discovered planet Neptune is found at mean distance to be rather more than thirty times the distance of the earth from the sun, and the star Centauri is about 7,500 times further than Neptune. But the comet of 1844 (ii), when at its greatest or aphelion distance, is nearly one-fiftieth part as far away from us as Centauri; and it is quite probable that the influence of solar attraction pervades an area of spherical space all round the sun, equal in diameter to at least one-twentieth part of the distance of *a* Centauri, and would therefore draw all weaker bodies toward it which happened to come within the limits of that area; while in like manner the sun, with its attendant planets, would be liable to be drawn by any body of greater power impinging upon the same spherical space. These facts, thus associated, aid to illustrate each other, and serve to show that the distance of the fixed stars is, in all probability, and taking the magnitude of many of them into consideration, a provision for the stability and regularity of our system of the highest providential importance. The nearest star after *α* Centauri is 61 Cygni, which, however, is more than one-half further away than the former, or 366,000 times more distant from us than the sun. It is in the northern hemisphere, in the constellation of the Swan, and is visible in a clear night as a small star of the sixth magnitude. But not very far distant from it may be seen a bright first-magnitude star, called Vega, or *α* Lyræ, about fifty degrees from the Pole star in an opposite direction from the constellation of Orion. This conspicuous star, the only one of the first magnitude within a circuit of thirty degrees all round it, is the seventh in point of known distance from our world. Its distance, ascertained by W. and O. Struve, is nearly six times that of *α* Centauri, or 1,337,000 times further than the sun, a distance stated at length of 129,689,000,000,000 miles, or about 120 times greater than the diameter of that area within which we have assumed the range of solar attraction to prevail.

The next star whose distance has been ascertained is Sirius, the brightest of all the fixed stars, conspicuous in the latitude of London during the winter months, where it appears a little downward and eastward from the great constellation of Orion, then prominent in the southern quarter of the heavens. This star, otherwise known as *α* Canis Majoris, or the Dog star, is a little further distant than *α* Lyræ. It has been ascertained by Henderson and Peters to be 1,375,000 times the distance of the sun (or the semi-axis of the earth's orbit), which would represent a distance of 130,625,000,000,000 miles. And here we come upon a star system of ascertained

Key to Plate II (to be placed behind Plate II) So that on looking through both between the eye and the light the names of the stars may be seen beside them.



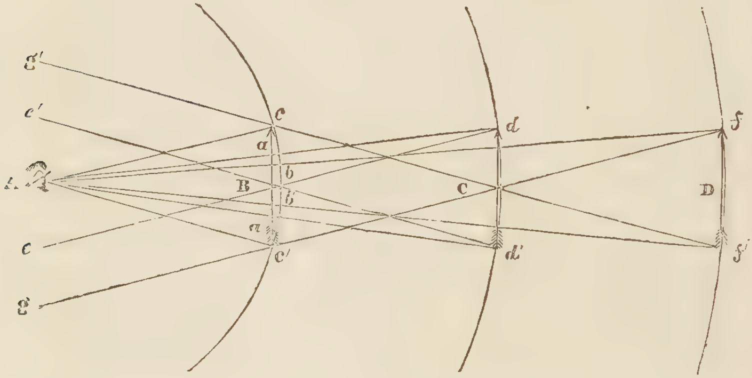
Key to the accompanying Star Map. Only the more conspicuous Stars are delineated in the Map to enable the reader to familiarise himself free from all confusion with their principal groupings. The Zenith of an observer in London is that given. The observer must keep in mind that all the stars given change their positions and perform circles round the Pole Star. From the position of the Zenith, it will be understood that the Map embraces more than can be



Map shewing the relative positions of some of the [illegible] and peculiar interest, an inversion in some respects of our own solar system; for it has been definitively ascertained that Sirius is one star only of a binary star system, and revolves round a darker star, hid altogether to ordinary vision by the brightness of its rays, but dimly visible to powerful telescopic investigation. Round this darker star Sirius performs an orbitual revolution in a period of about fifty years, moving at the rate of about seven and a half degrees per annum, or about fourteen miles per second. The distance of Sirius from the dark but principal star of the system, or rather from the common centre of gravity between them, is said to be about three and a half seconds, which may be taken as the semi-axis major of his orbit for the present. This, at the distance of Sirius, would fix the radius of his orbit from the common centre of gravity at about 2,467,000,000 miles, or approximately the distance of Neptune from the sun. But Sirius traverses this orbit in less than a third of the time required by Neptune to complete his revolution. What is however most peculiar and remarkable in this binary combination is, that we have here a luminous planet revolving round a relatively dark sun; for though the common centre of rotation seems to be external to the masses of both Sirius and his primary, and to lie between them, there can be no doubt that it is quite near to the darker body, while it is about two and a half billions of miles distant from Sirius. We can form some idea of the effect of such a combination if we imagine our own sun to be a comparatively dark or non-luminous body, and his light to be transferred to the exterior planet Neptune. This would make the whole solar system dependent, not upon the sun, but upon Neptune, for its light; and the only body which would in that case receive a regular amount or quantity of light in the solar system would be the sun itself, because the sun would never vary in its distance from Neptune further than the eccentricity of Neptune's slightly elliptical orbit. All the planets of the system would be alternately at the points of conjunction or opposition with regard to Neptune, which would be points varying in extent to the amount of the entire axis major of their orbits. In the case of the earth, we should at times be about 190,000,000 miles further away from Neptune than at other times, and the light he could give to us would therefore proportionately vary in quantity. At the same time, our nearest point to Neptune would never be less than about 2,650,000,000 miles, or about twenty-eight times more remote than our distance from the sun. This, even if Neptune were as large as the sun and as luminous, would give us so feeble an amount of light that the earth would be plunged in the perpetual gloom of a dim and dismal winter, which would desolate its whole fertility, and render it sterile and uninhabitable. Even Uranus, the nearest planet to Neptune, would, at its conjunction, be about one billion of miles distant (ten times further than the earth is from the sun); and when in opposition, or at the other extremity of its orbit, would be about four and a half billions of miles away (fifty times our distance from the sun).

While, astronomically speaking, stars are classed as suns, and Sirius, as compared with our sun, is certainly entitled to that distinction; yet if the primary bodies of each star system are to have the precedence, there can be no doubt that more strictly Sirius is only a light-giving planet to an otherwise comparatively dark system. At the same time, though manifestly of a greatly inferior gravitating power to his dark primary, Sirius is undoubtedly possessed of great size, and of a most brilliant illuminating power, which in all probability compensates largely for his occupying such a position in the system to which he belongs, as we have just illustrated by the supposition of Neptune being invested with the attributes of our sun. Indeed, we have the best astronomical reasons for believing that our own sun, at such a distance from us as Sirius, would appear as a star of very inferior magnitude.

It has been said, by Wollaston, that the apparent diameter of Sirius does not exceed the fiftieth part of the second of an arc; but even this at the immense distance at which Sirius is placed would give a spherical bulk about 1,700 times greater than that of the sun, and so render Sirius with his intense light a most formidable luminary to his system. Unfortunately, however, this estimate of his size cannot be relied on to any extent, and we have no means of knowing absolutely the sizes of any of the so-called fixed stars. They are all at distances far beyond the vanishing points of their bodies, and never, under the most powerful telescopic investigation, reveal any discs or hemispherical appearances like our sun and moon and planets; so that Sirius, when proper means of observation are taken, so far from revealing a diameter one-fiftieth part of the second of an arc, has his whole apparent size reduced to the minutest point of mere stellar light. The intensity of his light, therefore, is a much more reliable test of the superiority of this brilliant star than anything we shall in all probability ever be able to say of his size. This will be better understood by considering the condition of a body beyond the vanishing point of its size, but within the vanishing point of its light; for the vanishing point of light depends on the intensity of the particular light, while the vanishing point of a body depends upon size and distance under a fixed geometrical law. The reason why a body appears to diminish in size by the effect of increasing distance is that the angle of vision becomes more acute as the object recedes, until at the vanishing point it becomes so acute as to cease to be any appreciable angle at all. Onward to the vanishing point the whole apparent surface or disc of the body gives forth the rays by which it is seen; but beyond the vanishing point, supposing its light to be very intense, it has passed the point of appreciable angularity, and much of the radiation which up to the vanishing point it gave to the observer passes him altogether under the same angularity under which it proceeded before, and only some of those rays which are almost strictly parallel rays, reach him. This will appear more clearly from the study of the following diagram.



It will be seen from the diagram, that a body whose diameter is of the dimensions from *c* to *c*′, at the distance of B from the observer at A, will be diminished to the apparent diameter of from *a* to *a*′, when removed from the observer to the distance of C, and will be further diminished to the apparent diameter of from *b* to *b*′, when removed to the distance of D; but this diminution in apparent size or magnitude is not the only weakening influence on the visibility of the object: for it will be also found, on again investigating the diagram, that the greater portion of the angular rays of the object at B pass the eye of the observer when the object is removed to C; that is, all the rays between *d* A *e*, and between *d*′ A *é*; while all these rays entered the eye and contributed to its power of vision when the object was at B. In like manner all the angular rays between f A g, and between f' A g' pass the observer's eye when the object is removed to D; though all these entered it, and contributed to its power of vision when the object was at B. But while this shows that the visibility of the object not only diminishes on account of decrease in its apparent magnitude, inversely as the squares of the distance, as well as on account of a collateral decrease in the number of rays that reach the eye of the observer, it also shows that where at last the apparent magnitude of the body is reduced, as it is in Sirius and the other fixed stars, to a mere point of light in which no disc is discerned, all the angular rays of the object must then pass the eye of the observer, and none but parallel rays can reach him. It consequently follows that the rays of a fixed star cannot produce a focus or focal image in the telescope, and therefore cannot pourtray a figure of the object, or delineate its disc; and that its existence is revealed to us merely by the intensity of its direct or parallel rays, and exclusive altogether of its angular rays. If all the rays which reach the observer's eye at the distance B reached him, also at the distances of C and D, then there would be no diminution of the object's brilliancy at these remoter points; for light does not diminish in *intensity* by distance so much as it becomes less in *quantity* from diffusion under the dispersing effect of distance.

From the preceding explanation it will be gathered, that while we have a very inadequate idea of the size of Sirius, or the quantity of his light, we have the very strongest evidence of its intensity. We can approach the subject, however, in another direction. It has been already indicated that the spherical area throughout which the attractive power of our sun prevails is at least more than 1,000,000,000,000 miles in diameter, and this estimate has much probability in its favour from the sun's known influence over ascertained cometary orbits. The distance of Sirius from the outer boundary of this area is 130,125,000,000,000 miles, and we are not within the range of his attraction or that of his primary. The range of their attraction, therefore, cannot embrace a wider area than that of which this external distance would be the radius; and consequently the diameter of their area of attraction cannot exceed about 260,000,000,000,000 miles, or 260 times the range of the sun's attraction. Now, the densities being assumed to be equal, were Sirius twice the diameter of the sun, and consequently eight times his spherical size, he would, at the distance of Neptune from his pimary, require that his primary to retain him in his orbit should have at least something like the proportion to himself that the sun has to Neptune; that is, that the primary should be 16,000 times greater than the secondary. In short, the primary of Sirius would require, in that case, to be about 64,000 times the size of our sun; and as we have already shown that he cannot, at the ascertained distance of Sirius, have a greater area of attraction than 260 times that of the sun, we have, therefore, only to calculate what this enormous comparative size, or attractive power, which is the same thing, would give him; and as the power of gravitation, or attraction, diminishes inversely as the squares of the distance, a body to occupy an area of spherical space equal to 260 times that of the sun would require to have 260 × 260 times the mass or attractive power of the sun; that is, it would require to have 67,600 times the mass, density, or attractive power of the sun; for it might be, of course, of the same density and so much larger, or of a much greater density and proportionately less in size. It will from these figures be seen that there is no probability, brilliant and conspicuous as Sirius is for his distance, that he is more than twice the diameter of the sun in size or density or attractive power, as the case may be, although his light must be vastly more intense and brilliant. It is quite likely, however, from other considerations, which will afterwards appear, that the binary system of Sirius does not possess an attractive power so much in excess of that of the sun as here indicated, and that both he and his primary are, therefore, to be reckoned as so much less in density or in size. Thus, Arcturus (α Bootis) is about 70° distant from Vega (α Lyræ) before mentioned, and both are about equal in distance from us with Sirius, Vega being 127,015,000,000,000 miles distant, somewhat less than the distance of Sirius; and Arcturus 154,280,000,000,000 miles, or somewhat more than that of Sirius; and as both Arcturus and Vega have proper motions —Arcturus moving at the rate of fifty-four miles per second, and Vega at the rate of thirteen miles per second, and are therefore, in all likelihood, star systems similar to Sirius, and in all respects as great and important in all their elements, it would follow that if Vega and Arcturus had areas of attraction similar in diameter to that of Sirius, above supposed, they would invade the regions of attraction of each other; for it is not probable they can be much more than 185,000,000,000,000 miles distant each from the other; and if each had an area of attraction 260,000,000,000,000 miles in diameter, they would thus be 75,000,000,000,000 miles within the range of each other's attraction. Dividing the distance between them, therefore, as more near the truth, for they certainly exhibit no indication of mutual attraction, the area of their respective attractive powers could not be greater in radius than 90,000,000,000,000 miles; and in like manner the Sirius system has probably no greater semi-diameter than this also, though even that radius may be greatly more than the truth. Thus we at least approximate facts by collateral means, which are beyond the range of direct investigation, and come to the reasonable conclusion that, notwithstanding the brilliant power and intensity of his light, Sirius cannot be in mass or density greatly, if at all, larger than our own sun. That he should be smaller, we can hardly conceive, compatibly with the fact that he shows greater relative intensity of light from a distance beyond the vanishing-point of his disc; but even taken at the same size, the mass, or density, of his dark primary would still be immensely great, and probably, as we have indicated, at least sixteen thousand times that of the sun. Indeed, everything conduces to show that the great star systems are composed of bodies of stupendous size and grandeur, compared with the members of our own.

Coming next to Capella (*α* Aurigæ), which is about three and a quarter times further distant than Sirius, though even from that immensely remote region of space it exhibits the intensity of light which entitles it to be ranked as a star of the first magnitude, we have here again an instance of a star with a proper motion, its velocity being that of thirty miles per second. Sir William Herschel was long since disposed to consider that Vega, Capella, Arcturus, Sirius, Canopus (*α* Argûs), Markab (*α* Pegasi), Bellatrix (*γ* Orionis), Menkab (*α* Ceti), Schedir (*α* Cassiopeiæ), Algorab (*δ* Corvi), and Propus (I Geminorum), were centres of separate and extensive star systems. How far this is the case with regard to Sirius has been already indicated. With regard to the others, much has yet to be observed before we can say whether their motions are properly those of planets or secondaries, as for distinctiveness we may be permitted to call them, or those of primaries, gravitating in a stellar procession in common with our own sun, as we shall in an after place have to explain.

To return to Capella, which is a brilliant star in a direct line between the constellation of Orion and the Pole star, and may be seen passing the zenith nightly during the London winter. We have said that it is about three and a quarter times more distant than Sirius; in other words, it is

295,355,000,000,000 miles further away, a distance which Sirius, travelling at the rate of fourteen miles per second—the rate of his speed in his orbit—would require about seven hundred thousand years to traverse outward from us. Now there is little doubt that long before completing this immense journey Sirius would be utterly lost by invisibility to our view, and hence it follows that Capella, though not quite so brilliant as Sirius in its present relative appearance, must be incomparably the brighter, and probably also immensely the larger, star of the two. What the area of attraction of such a star must be it is vain in present circumstances to imagine; but the reader may at least conceive that the spherical spaces set apart for each of these systems must form an enormous whole, when he is told that the double stars, now recognised to have distinct orbitual motions, and therefore to form separate star systems all around us, are upwards of 600: so that we are surrounded with 600 star systems, each occupying separate areas of attraction of probably 180,000,000,000,000 miles in diameter each; that it is through and beyond this surrounding region of stupendous immensity that we reach the remoter and dimly nebulous regions of astronomical space, and that our means of vision employed for that purpose in any direction have probably to traverse more than ten of these areas of attraction in direct line before encountering any nebulosity.

To attempt to form any idea of a spherical space 3,600,000,000,000,000 miles in diameter, eight times the distance of Capella, would of course be utterly hopeless; but let us trust that the elements of which it is composed (as before stated) are not without their aid to the mind, and supply some legitimate astronomical criteria and standards of comparison which are quite likely far within the truth. Many of these star systems are found to consist of more than two, and often comprehend three and four or more stars, when they are called ternary, quaternary, etc., or multiple systems, and must have proportionately more extended areas of attraction. Let us refer for an instance of this to the magnificent trapezium, as it has come to be called, near the centre of the great constellation Orion. This, at one time marked in star catalogues as a single star with the Greek letter Theta (θ Orionis), was discovered by the help of more powerful telescopes to consist of four stars forming the angles of a trapezium. Telescopes of six inches aperture showed two additional stars of smaller magnitude, making the trapezium a sextuple system; and Mr. Lassel has more recently discovered a seventh star, making the system a septuple one. Before this last discovery Humboldt had said, "Probably the sextuple star θ Orionis constitutes a real system, for the five smaller stars have the same proper motion as the principal;" and on this fact astronomical attention is at present fixed with intense interest. Here then we have, in every likelihood, a system of seven suns at a distance as great as Capella, and possibly much greater; and the area of attraction of which must be far in excess of the diameter we have been assuming in the preceding remarks as the average area of the star systems; for the apparent distances of the seven stars of the system from each other would alone occupy a large portion of such an area.

Nor is this a solitary example; for, according to Struve, the star Castor (a Geminorum) is one of a ternary system consisting of three suns, the third being about fifteen times more remote from the first than the second. This star has completed an entire revolution in its orbit since 1790, and so also have the separate star systems ξ Ursæ Majoris, whose period is 63 years, η Cassiopeiæ, and p Serpentarii. The periods of other double stars have also been ascertained, of which 61 Cygni, whose distance we have already given, has a period of 452 years; p Ophiuchi, a period of 92 years; ζ Cancri, 59 years; ζ Herculis, 36 years; μ Coronæ Borealis, 66 years; γ Virginis, 150 years; and α Centauri—the nearest of the fixed stars, already mentioned—whose period of revolution is about 79 years.

From these it will be seen that the criterion of Sirius, which we have adopted, with his period of 50 years, is not above the probable average of the star systems, but much more likely below it. And if we are to assume that these periods have some reference to the distance of the respective stars from their primaries, or from their common centre of attraction—as we find to be the case in the solar system—then we must accept the fact that the system exhibiting the longest period must in all analogical probability be immensely larger than those with short periods. So that 61 Cygni, though nearer to us than Sirius, would be a system much more extended, and having consequently a larger area of attraction around it; the period of Sirius, as already stated, being only 50 years, while that of 61 Cygni is nine times longer, viz., 452 years.

CHAPTER III.

Reconsideration of the space occupied by the known Star Systems immediately around us—Relation of the Star Systems to each other, and to a common centre of attraction or Central Sun—Position of the Central Sun—Its possible magnitude and invisibility—Our Sun's Orbit round the Central Sun—The Magellanic Clouds or Nubeculæ—Their distance—Nebulæ beyond them.

In the preceding chapter it has been intimated that we are so thickly surrounded with binary, ternary, and other multiple star systems, that we have probably to gaze through ten of these in a direct line, with an average diameter each of 180,000,000,000,000 miles, as proximately that of their surrounding areas of attraction, before we reach or are able to perceive any of the stellar arrangements and nebulæ beyond them. Let us consider, from well ascertained astronomical data, how far we have kept within the limits of moderation in coming to this conclusion. It has been already stated that the distance of the nearest fixed star, *α* Centauri, is 21,280,000,000,000 miles; and it was assumed with reasonable probability that the area of attraction surrounding the central body of our own system was at least 1,000,000,000,000 miles in diameter. Taking the radius or semi-diameter of this area as the portion of it extending outward from the sun toward *α* Centauri, we should still have 41,560,000,000,000 miles for the diameter of the area of attraction of *α* Centauri; and deducting this sum from the distance of Sirius, we should have a balance left sufficient to give 188,300,000,000,000 miles for the diameter of the area of attraction of Sirius.

Deducting the distance of Sirius from the distance of the Pole star (Polaris), which is ascertained to be 292,410,000,000,000 miles, and also deducting the semi-diameter of the area of attraction given for Sirius as above, as that portion of it which extends outward beyond him, we have still enough left to give a diameter of 125,440,000,000,000 miles for the area of attraction of Polaris. Making a like deduction of distance of Polaris, and the semi-diameter of its area of attraction from the distance of Capella already given, we have as much over as would leave an area of attraction to Capella of 339,420,000,000,000 miles in diameter. These four areas of attraction give an aggregate of 695,500,000,000,000 miles, and an average diameter of 173,887,000,000,000 miles for each; and yet we have here, supposing the confines of their areas to be so close as to be all touching each other—which there is no probability that sidereal areas of attraction do—only reached the fourth area of attraction outward from our system, to find it the region of a star of the first magnitude.

The patient and industrious W. Struve, who has laureled his name with astronomical achievements, found, after thirteen years of persevering vigil, that out of 120,000 stars, 3,000 were certainly double. We now have record of more than 6,000 optically double stars; and of these more than 650 have been ascertained to consist of binary or other multiple star systems, physically connected together, as we have explained Sirius and his primary to be. How much this number may yet be increased by further astronomical observation we can hardly anticipate, but increase to a very great extent is obviously certain; and indeed the doubt is rather suggested, whether it be not owing to the deficiency of our telescopic power that we have not been able to discern that every solitary star is only a member of a system, to which it forms either a primary or a secondary in a connected arrangement. It appears thus very certain that the assumption of a space equal to the areas of attraction of ten such star systems, prevailing in each direction around us in direct line before we reach the region of the nebulæ, is much within the limit of the facts.

Let us, however, rest content with the estimate adopted, and in the meanwhile, and for a moment, endeavour to strain our vision outward through this dense stratum of sidereal universes to the luminous haze of nebulosities beyond; and for the purpose of aiding us in this new region of immensity, let us endeavour to construct a few mental standards to carry with us as we go. The mind of man is capable of making a bold flight after truth, and it is still a region of fact we are exploring. We may not be able either to measure or even imagine its maximum, but of its minimum we may be able to say it cannot be less than this or that criterion which we are privileged to apply to it.

The sun has been found to have a proper motion in space, at the rate of about four miles per second, or 14,400 miles per hour. This motion has been suspected, by the most eminent astronomers, to be a motion in an orbit, of which the whole members of the solar system partake in co-operation with their primary; and this suspicion is fully justified by all the analyses of astronomical motion with which we are acquainted. Astronomers do not yet know of any heavenly body, with whose motion they are *fully* acquainted, which does not move in an orbit. The centre of attraction to the suspected solar orbit is believed to be in the region of the Pleiades; and the present direction of the sun's motion has been ascertained to be toward a point in the left thigh of the constellation Hercules, about midway between Vega (α Lyræ) and Alpheta in the Northern Crown. In the Pleiades, then, or in this direction somewhere, it is concluded that our solar system has a centre of attraction round which it revolves, in addition to all its other complicated orbits and motions within itself, at the rate of something more than three-fourths of the diameter of the earth's orbit per annum. If others of the star systems, such as those of Sirius, Capella, Polaris, etc., are equally affected by the same centre of attraction, but at different rates of velocity, what can we conceive of the orbit of our own small sun, and of this new combination of all these great star systems into one more extended and predominating system of which they are all, taken separately, mere limited portions?

To approximate this question somewhat nearer, in the first place we will take the moon's diameter as thirty-two minutes (32′), it is nearly so. Assuming then that the central object or influence round which the sun performs its orbit is only the distance we have already estimated, that of ten star systems and their areas of attraction from us, or 1,800,000,000,000,000 from the sun, two stars at that distance, no further apart optically or to appearance than a thirty-secondth part of the apparent diameter of the moon, would be in reality about 600,000,000,000 miles apart, or about 200 times the distance of the planet Neptune from the sun; and a body at this distance presenting a disc the apparent size of our moon would have a diameter of nearly 20,000,000,000,000, or very nearly a diameter equal to the distance between us and the nearest fixed star, α Centauri. How easy is it with facts like these before us to understand that at such a distance some comparatively non-luminous or dim central sphere, like the primary of Sirius, may exist in the region of the Pleiades, ponderous enough to draw the whole multiple star systems we have mentioned, along with our own solar system, into orbits around it, at the various rates of their known proper motions, and yet this huge centre of attraction be in itself small enough to elude for ever all astronomical detection in the spacious obscurity of its remote and mighty solitude! The orbit of our sun in such a case would have a probable diameter of 3,600,000,000,000,000 miles, and this orbit it would traverse in a period of one hundred millions of years at the (runaway railway!) speed of 14,400 miles per hour! Can the reader, by looking at such a line of figures as 1,800,000,000,000,000 miles, at once comprehend the enormous meaning and magnitudes it contains, and that the central point of the sun's orbit is ninety times the distance of the nearest fixed star, *a* Centauri, and about one thousand eight hundred times the minimum diameter of the sun's area of attraction; or that it is six hundred and seventy thousand times the distance of Neptune from the sun, and penetrates into a remote region of space two hundred millions of times more remote than the sun from us? The sun and the earth at the opposite sides of this immense orbit would be four hundred millions of times further distant from each other than they now are.

Let us now suppose an astronomer situated at the opposite site of this mighty orbit, gazing at the sun across its diameter for a hundred years, and endeavouring to ascertain the rate of its motion—assuming that its light could be rendered visible to him at all at that enormous distance. What would he find the result of his century of vigil to be? At the end of that long weary watch we fear he would only be able to add to the records of his science that which the sun had not done; namely, that during the whole period it had not moved a distance equal to a ten-thousandth part of the apparent diameter of the moon: and he would retire from his task in doubt whether it were not literally a fixed star without any motion at all, although it had really moved more than 12,500,000,000 miles in the period across the field of his telescope without his being able to detect that it had changed its position. From these data the reader will have some idea of the difficulty the astronomer has to encounter when he endeavours to reduce to fact and precision elements of his science so extremely remote. His standards fail him, his mensuration becomes as powerless as "a peacock's feather to fan the sun;" he can only grope with some little light and guidance from analogy the immeasurable vagueness and vastness around him. To gratify the straining and thirsting mind it is perhaps fortunate after all that parity of reasoning has some legitimate alliance to exact logic, and that the fancy can roam a little way in this direction, even where the facts are altogether too stupendous for its grasp. But what may the highest conception of imagination be here but a wonder-exhausted minimum of the truth! A brilliant soap bubble, enclosing a little space, and dreaming it is gauging infinitude.

An orbitual journey before the sun of a hundred millions of years! and the system yet but seven thousand years old, and already so full of histories—so fractured and disrupted with fragments and ruins—obliteration and oblivion! Will our precious luminary accomplish the race set before him? will he keep his watch-fire burning? Philosophers have already doubted whether his luminosity has not begun to weaken—whether his power of combustion may not be exhausted within a given and conceivable time. However that may be, and we may have occasion to allude to it again hereafter, a hundred millions of years is no trivial or unvenerable cycle for even the brightest and most vigorous powers to be tested by. It is very certain that, so far as this world's affairs are concerned, man's highest energies in their best development would be unable to grapple with the details of so long a history, and it is quite possible to conceive that on such a pilgrimage the sun himself might "grow dim" with age, and that the spheres dependent on his lustre might cease to contain the subtle element of vitality; that our little region of sun-light might become a spectral system, a grimly marshalled array of worlds of the silent and the dead, draped in funereal darkness amid the universal starlight, still performing under the great law of gravitation their interlaced and complex orbitual motions, and in this strange and mazed dance gliding like a set of phantoms through eternal night! Worlds, whose graves are filled, do they necessarily also come to an end? Nature and science cannot answer the question. The interested and reverential mind must seek its solution elsewhere. It is possible that man may yet be privileged through the light of his immortality to see this mighty orbit fail in its completion, and the sun and his attendants break down on their journey, and give way to re-arrangement; for to the POWER which set these things in order we can conceive no limit—the will of that POWER *must be supreme.*

But we will now endeavour, if we can, and with the standards we have been forming for ourselves, to creep out a little further into the grey starlight of this ever-expanding infinitude, and see whether there be anything of which we can yet form some little and feeble comprehension. We will turn attention, then, for a moment, to the Nubeculæ, or Magellanic Clouds, as they are called. These are two luminous clouds, as bright as the Milky Way, occupying places in the southern heavens, very near to the South Celestial Pole. The centre of the larger nubecula being about 20°, and that of the minor nubecula about 15° from the pole. The larger nubecula covers about forty-two, and the smaller about ten square degrees of the heavens. The larger of these nubeculæ is not rendered invisible to the naked eye even by the strongest moonlight, which cannot be said of the Milky Way, or of any other nebulous appearance whatever. It may be considered reasonable, therefore, to assume that we here encounter the nearest nebulosity to our system. Its real distance, however, is yet unknown; but with the aid supplied us by Sir John Herschel, in his "Cape Observations," let us try to understand some of its known features. Near the centre of this larger nubecula, Sir John informs us he found a nebula not more than a five-hundredth part of the whole cloud or nubecula, which contained as many as 105 stars from the fourteenth to the sixteenth magnitude, distinctly standing out and relieved from the unchequered, uniform, and wholly unresolved background beyond them. Let us endeavour to analyse and reduce these facts to our comprehension. The size of this nebula is, say a five-hundredth part of the size of the whole major nubecula: that is, the five-hundredth part of forty-two square degrees, or about thirty square minutes; or, proximately enough for our purpose, about a third of the moon's disc in apparent size, and in this space there is interposed between us and the nebulous background about 105 stars from the fourteenth to the sixteenth magnitude. Let us assume those stars to be no further distant from us, to begin with, than what we have supposed as the distance of the great primary influence in the Pleiades, round which our sun performs his orbit, or 1,800,000,000,000,000 miles, and what will we find? We may reasonably assume these stars to cover a circular area of about ten minutes in diameter (10′) with about thirty-five stars in line on the diameter, and each of the 105 stars about 170,000,000,000 miles apart from any of the others, assuming them to be all about equally distant from us. Thus each of them would be only about a one-hundred and twenty-sixth part of the distance from the others that the nearest fixed star, *a* Centauri, is from us. Is it at all probable they can be so near to each other, unless they form one connected multiple star system of 105 stars; a thing possible indeed, but utterly unparalleled as yet in all our knowledge of the heavens? Either this must be a star system of matchless magnificence and brilliancy, or our estimate has been a feeble instead of an excessive one of the distance of these stars from our own small world. We fear it is in our moderation that the error will be found, and that all the probabilities condemn the lowness of our estimate.

Let us assume these stars to be each as far apart as *α* Centauri is from the sun, which is quite as fair a probability at all events, for that is the shortest distance we are aware of yet between star and star, unconnected in binary or other multiple systems; and let us then consider what their general distance must be from us. We will find on the data already adopted for the lower estimate, that such a distance between star and star of these 105 stars would give a circle whose radius, holding our position to be its centre, would be about 200,000,000,000,000,000 miles, or more than a hundred times the distance of that central influence in the Pleiades, round which our sun is suspected to revolve, as before stated, and this would be the general distance of the stars interposed between us and the central nebula of the great nubecula. To reach them, therefore, would be equivalent to looking through a thousand sideral areas of attraction in direct line, of the size and diameter we previously adopted.

How little can we conceive of the size of these immensely remote stars, or of the enormously concentrated intensity of their light, if that be indeed the quality which makes it travel so far! And yet, at this mighty distance, we are only in the region of stars of the fourteenth and sixteenth magnitude, with a nebulous background far out beyond them, unchequered and uniform in its luminosity, and, to all our optics, yet wholly irresolvable—a dense beach of glittering star sand—an impassible stratum, apparently composed of heaped and piled and accumulated suns, hurled together one might almost conceive by some mighty storm-wave which had passed along the ocean of eternal space, and dashed them together, like a sand-bank, in the great gulf of infinitude. True, spectrum analysis has said something of what still unresolved nebulæ may be composed, and we shall have to give due attention to that in its proper place; but fully admitting the extraordinary achievements and merits of spectrum analyses within their known and proved limits, we may be permitted to doubt whether this new mode of investigation can justly claim credit for absolute accuracy here—it being a mere optical power—where all other optical power, even on the most gigantic scale, has utterly and helplessly failed.

What, then, are we to say of the distance of this nebula in the great nubecula? How can we measure it? what can we conceive of it? If we fall back on Sir William Herschel's early idea, that these unresolved nebulæ are composed of uncondensed matter, as yet unformed into stars, what may be the dimensions of such a mass of matter floating at such an enormous distance? and what may account for its intense luminosity shining out to us from afar, undimmed by the strongest moonlight, unpaled in its lustre by the brilliant light of nearer and intervening stars? Such a nebula as this alone, if composed of uncondensed stellar matter, must have a diameter equal to 650,000,000,000,000 miles, assuming it to be no further distant than that already estimated for the 105 stars, which stand out in relief between it and us, a diameter more than half as great as the distance of Capella from the earth; and yet this nebula is, as Sir John Herschel tells us, not more than a five-hundredth part of the whole major nubecula. We shall hesitate to believe such a space as that filled by either of the nubeculæ to be occupied with uncondensed stellar matter, spectrum analysis notwithstanding, until we find spectrum analysis applied to it on a scale more gigantic than that of Earl Rosse's great telescope, with all other corresponding optical appliances, on an equally magnificent arrangement, brought to its aid. Spaces so vast as these are not likely to be altogether void of fully formed and developed stars; and what they should do, or how they should exist, in a haze of uncondensed matter as brilliantly luminous as their own light, and which luminosity is visible from as great distances in the remote regions of space, would be a very difficult question to answer. It is far more reasonable, in the meantime, to suspect that the discriminating powers of spectrum analysis fail, where all other optical powers fail, and that in regions so immensely distant spectrum analysis cannot accomplish more than the telescope in the resolution of nebula, where stars are mingled with stars, and their light inseparably mingled and blended together. But we will endeavour to do more justice to this subject in its proper place.

According to the standards we have already adopted to enable the reader with some breadth of view and power of associated comparison to reach the distance we have now penetrated, that of the 105 stars interposed between us and the central nebula of the great nubecula, we have arrived at a region where bodies, billions of miles apart from each other, if composed of increasingly remote stars, so nearly in line with each other, would have the apparent distance between them so diminished by perspective as to be indistinguishable and incapable of appreciable resolution, or distinctive separation ; before reaching which, bodies vastly more magnificent in dimensions than our own sun would long have ceased to have either apparent disc or apparent dimension of any kind ; and where luminosity vastly more intense and powerful than his would have utterly failed to be visible, and have become no better than an extinguished taper in the ebon obscurity of night. Yet even here are to be found stars distinct and clear, shedding their vestal lights pure and far across the mighty space which would otherwise darken, like a funereal pall, in the great shining chambers of infinitude.

In our next chapter we will endeavour to comprehend something of the principle or order in which the great star systems are arranged with reference to each other, and to their own proper and respective orbitual motions, that we may be enabled after that, with some added light and criteria, to go fully into the wonderful subject of the nebulæ.

CHAPTER IV.

Proper and Orbitual Motions of Stars—Their relation to a Central Sun or Centre of Mutual Attraction—Rates of Proper Motion of Stars—Possible Positions with reference to each other in a Central Sun System—Coloured Stars—Variety, Intensity, and Distinctness of their Colours—Cause of their Colour—Stars Changing their Colours—Periodical Stars, and their Orbits—The Planets and Planetary Motions of Star Systems—Their Comets—Possible cause of Star Haze observed by Mr. Hind.

In treating of the star systems, we have hitherto mentioned them as consisting of binary, ternary, and other multiple arrangements. But it would be a great mistake on the part of the reader to assume from this that there are not other star systems which reveal but one star to us, forming, like our own sun, in all probability, the central luminary of a system dependent entirely on it for light and heat, and revealing no orbitual motion, and also in many instances so distant as to exhibit no proper motion which our means of observation are capable of detecting; appearing, in short, as far as we can judge of them, to be distinctly isolated and absolutely fixed stars.

And here, as we have used the terms orbitual motion and proper motion more than once in the course of preceding explanations, it is time that a definition should be given of what is meant by these terms as distinguished from each other. By proper motion, then, is signified such a motion as our own sun has in space, at the rate of four miles per second, or

14,400 miles per hour, as before mentioned, and which must be produced by some source of attraction external to, and altogether independent of, the physical system of planets and satellites by which he is surrounded, and of which he is the chief member. Astronomers justifiably suspect this to be, after all, an orbitual motion, as has already been stated, though so extensive that our powers of observation do not yet enable us to distinguish in it any deflection from a straight line. Had the sun, in addition to this, a motion in a small circle or ellipse, occasioned by the attraction of the planets by which he is surrounded—which he would have had if the gravity of his planets had been much greater or his own gravity much less—this would have been distinctively called an orbitual motion, as compared with the proper motion just mentioned. Indeed, he has a slight motion of this nature, but as its centre is within his own volume or mass it may be spoken of rather as a perturbation. On the other hand, Sirius, Polaris, *α* Centauri, 61 Cygni, etc., have each both orbitual and proper motions—Sirius having an orbitual motion completed in about fifty years, and a proper motion at the rate of twenty-nine miles per second, or more than seven times the rapidity of that of the sun; the proper motion of *α* Centauri is thirteen miles per second; Vega's is the same; Capella's, thirty miles per second; 61 Cygni's, forty miles per second, or ten times that of the sun; while that of Polaris is only one and a half miles per second, and that of Arcturus fifty-four miles per second, or fourteen and a half times that of the sun.

These facts will enable us now to consider more comprehensively the general aspect and arrangement of the star systems, and their mutual influences and dependence, if they have any, upon each other. The first question occurs then: Have these star systems, along with our solar system, a common, concurring, or coinciding centre of attraction with reference to what they are all engaged in—the performance of these proper motions, in which each is proceeding at its own respective rate of rapidity, and in which they all at length fall into elliptical orbits of undistinguishable immensity? And are we at present contemplating many of the systems at points of proximate conjunction with us, or in their perihelion passage, while others are at the aphelion point, or most distant portion of these orbits? They have all apparently orbitual motions as well as proper motions, just as our own system is full of orbitual motions, and partakes also of the sun's proper motion. Concurring so far, therefore, have their proper motions each a separate centre of attraction, or all one identical and common centre? This is a question which ages and generations yet to come will have to ponder over without being able to determine, if indeed it ever be determined by the observation of man; for it is here, and in presence of such problems, that, great as man's optical resources are, and mighty as have been his achievements, his boasted intellect becomes powerless, and, with a soul thirsting for knowledge and unsatisfied, he must look at the resources of science as impotent means, and its highest standards as imbecile appliances.

Nevertheless, analogy does not leave us absolutely powerless on this great question. It is at least reasonable to infer, as astronomers have done, that the whole probabilities are in favour of these proper motions being of an orbitual character, from the simple fact that no motion fully known to astronomy has ever been found to be of any other character; and if we are warranted in going thus far, we are also warranted by analogy in assuming that the bodies which move most slowly must be those furthest from the common centre, just as we find to be the fact in the solar system. On this principle, therefore, the order of distance would be inversely as the velocity, so that the more distant star system from the common centre would stand at the top of the following column, and the others in nearer proximity in the order in which they are arranged as the column descends :—

Polaris	$1\frac{1}{2}$	miles per second.
Sun	4	,,
α Centauri	13	,,
Vega	13	,,
Sirius	29*	,,
Capella	30	,,
61 Cygni	30	,,
Arcturus	54	,,

If so, and subsequent observations should fill up with intermediate velocities the difference between Polaris and the sun, the latter and *a* Centauri, and between Sirius, Capella, 61 Cygni, and Arcturus, respectively, we at length, by a comparison of the position of all these stars to some point in common, become able even to approximate the question whether the suspected centre in the region of the Pleiades be not the general direction round which the combined motions, tend. The labour before the astronomer in this department of his science is indeed one of almost appalling magnitude, but it is surprising what the human mind will attempt with very slight encouragement, or how much it will be even provoked and stimulated by any difficulty short of absolute and manifest impossibility.

If it should happen that Polaris is external to us, that is, has an exterior orbit to the sun in this general combination of the star systems into one, it would follow that the whole of the stars mentioned being at the perihelion, or nearer side of their orbits to us, their respective positions with relation to each other might be accounted for by their being in something like the points of their orbits indicated in the following diagram, which would account for their being seen by us at widely different angles and otherwise unaccountably irregular distances :—

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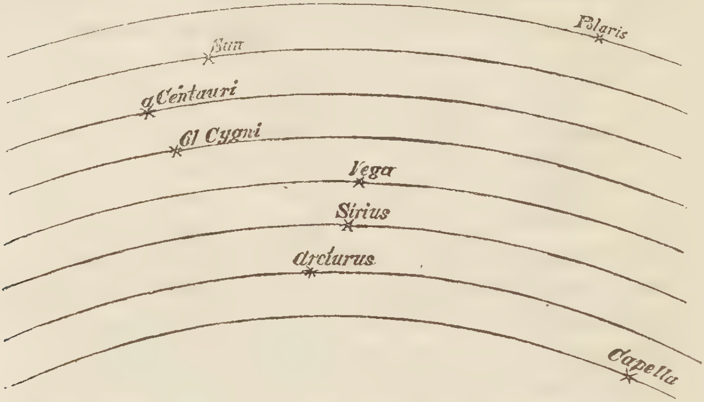
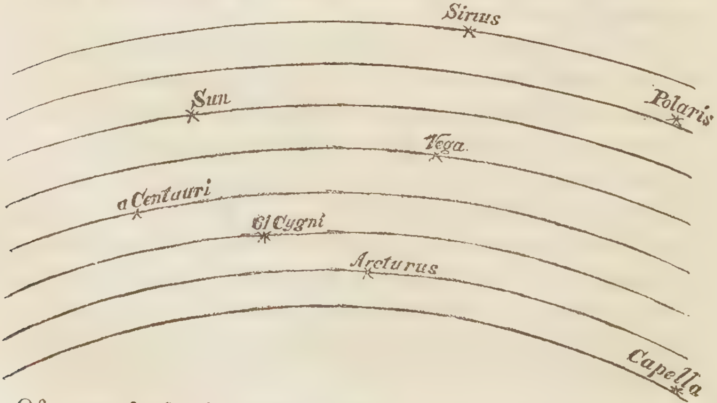
* The proper motion of Sirius is stated according to the latest conclusions of Mr. Huggins, confirmed by Father Zecchi from independent observations, showing the rate at which Sirius is receding from us (29·4 miles per second).



On the other hand, it is quite within the range of possibility that the positions of the several stars might be more nearly that indicated in the following diagram, and that in either case their rates of proper motion may be much concealed by the foreshortening of that part of their orbits which they are at present traversing, in our point of view ; just as our own planets sometimes appear almost stationary, when the direction of their orbits is nearly in line with our view of them.



Of course both of these diagrams are purely hypothetical.

These possible positions of the star systems with reference to a central sun, or source of common attraction, are, of course, still mere theory and speculation, and they are not intended to convey the apparent positions, but rather the real distances, of the stars with reference to us; the apparent position being dependent on the additional fact, not yet ascertained, whether all the star orbits in this system are in the same plane. This view, however, is not, as astronomers know, without many facts and analogies to support it, to which the recent researches of Mr. Huggins, hereafter more fully referred to, are giving great additional force; and every idea which analogy supplies is of importance at the present stage of this difficult inquiry, were it for nothing but its value in warning from the wrong road where it is found not to open up or indicate the right one.

Another remarkable feature of these star systems, and perhaps the most brilliant and intrinsically beautiful phenomenon of astronomy, is the resplendent and gem-like variety of colours by which the binary, ternary, and other multiple systems are characterized. Here all the colours and intermediate tints of the spectrum are to be met with, manifested with the richest intensity and the most vivid and distinctive strength and fulness of hue. Thus, in γ Andromeda we have a ternary combination, the brighter star being a rich and full orange, and the two fainter stars green. In σ Cassiopeiæ we have a bright blue and a sea-green star. β Cygni is a pair of stars, yellow and sapphire; α Ceti is a very fine orange star, with a blue companion; β Crucis is a white star, with an intense blood-red star in the same field; *R* Lepris is an intensely clear crimson star (known as Hind's crimson star), with a bright star in the same field; α Herculis is a rich orange, with an emerald-green companion; η Cassiopeiæ is a yellow star, with a purple companion; γ Leonis is a binary, consisting of a golden yellow and a reddish green star; Polaris, β Ursæ Minoris, Atair, and Procyon have a yellow or golden light; and a catalogue has been given of more than 300 red stars, ranging from full garnet, scarlet, vermilion, orange-red, full ruby, rose, pale rose, intense fiery red, blood red, intense sanguine, deep crimson, rich ruby purple, very ruddy orange, pure ruby, fine dark ruby, vivid red, intense scarlet, and intensely deep garnet, to every tint or delicate gradation from these which the most discriminating eye for colour can appreciate and perceive, and which language would fail to explain. In a celebrated cluster of stars near κ of the Southern Cross, there are about 100 small stars of different colours, from the various reds above mentioned to all the tints of green, blue, and bluish green, so crowded together that they appear in the larger telescopes like a piece of magnificent celestial jewellery, studded and flashing in the most superb splendour with the richest and most brilliant gem-light.

The reader can well imagine how dazzling this fine phenomenon of colour must be, when he bears in view that it is not like that of the artist's pallet, a dull pigment dependent on the aid of separate light thrown upon it for its intensity and power, but that it is luminosity realized—the living, flashing, and burning lustre of intensest sunlight itself—making all other colour and gem-light feeble before it! What the internal aspect of ternary and other multiple star systems so lit may be, is a dream far surpassing in magnificence all the glowing fancies and wonder-filled creations of fairyland. To many of such systems, with a scarlet, a golden, and a sapphire or an emerald sun circulating at widely different portions of the physical arrangement, the effect on planets—some, perhaps, intermediate between, and others beyond them—must frequently be that of a golden, a scarlet, and an emerald or a sapphire day alternately; sometimes that of a golden day and a scarlet night, with the cooling contrast of a sapphire or emerald dawn, or interposed period; and sometimes the cathedral splendour of all combined, filling the heavens with a mingled and saturating glory of every colour and hue. And if such colours add their glories to the landscape outlines, and lakes, and streams, and far-stretching shores and bays on which they fall, we can imagine how mountain peak and running water will be smitten into ruby, and amber, and amethyst, and violet, or dashed into a sudden spectrum of opal, or quickened with the coloured and swift-passing flash of the diamond, as the lights and shadows troop through the changeful sky. It may well be with the intensest sunlight for their sustaining power, that such colours shine out in finely divided yet full and distinctive tints, which in no other arrangement, and under no inferior brilliancy of lustre, could be distinguished by the finest and most critical eye. Hence we have garnet red, very fine deep garnet, full garnet, and fine ruby, fine dark ruby, extremely intense ruby, beautiful ruby red, intense ruby red, rich ruby, purple pure ruby, etc., etc., in language feebly endeavouring by strained expression to give adequate name to vividly clear and gorgeous distinctions, for which man's vocabulary has yet no fitting utterance.

Astronomy thus places it beyond all question that these star systems possess many inherent and widely marked elements of glory and splendour to which our little system, with its solitary sun, is a total stranger. It is true, we have the roseate dawn, the clear, pale, sultry noon, the golden sunset, richly associated with all the fiery splendour of the west, followed by the meditative twilight and the calm and soothing influence of the silvery and silent night; and better suited to us in every way, doubtless, is the arrangement to which we are subject; but the magnificent scale on which the larger elements of the universe are created, revealing system after system as gorgeous in permanent yet interminably changeful glory as clustering seasons of varying flowers, is not without the higher purpose of demonstrating the inexhaustible wealth and magnificence of their great Creator's power. Nor are they created in vain, even if such alone be their mission; for it must be the highest purpose and privilege of all creation to glorify its Maker. Nor is their mission wholly fruitless if they awaken even in one benighted heart the sentiment of adoration and praise, and the impulse to draw nearer to so beneficent a God.

Here, then, in the more near and immediate regions of astronomical space we have, wherever we turn around us, the Creator's power developed on a stupendously great and magnificent scale, with added attributes and characteristics foreign to all our experience, and forming peculiarities of intense beauty and interest, such as the imagination of the most powerful poetic minds will perhaps for ever fail even faintly to realize. W. Sturve has given a list of 596 double stars, of which he found that in 375 cases the two component stars had the same colour and intensity, in 101 cases they had the same colour but different intensity, and that in 120 cases the colours were entirely different. Of the first two sets having the same colour, and amounting to 476 of the whole 596 stars, 295 were white stars, 118 reddish or yellowish, and 63 bluish. Many of the colours were at one time supposed to be complimentary colours where the two stars differed; but this has now come to be regarded as doubtful even in any case, as blue, which would be the complimentary colour of a reddish yellow or orange star, is quite as frequently found associated with a pure white star as with a coloured companion; and solitary blue stars, as well as blue planetary nebulæ, do certainly exist, while there are many instances in a binary arrangement where both stars are blue. And the same thing may be extensively said of other coloured stars also. How far the colour is due to the state of combustion in the star is another and a much more difficult question to determine with our necessarily weak and imperfect means of observation; but it has certainly been ascertained that stars change their colours; so that strong probability points to changes in the condition of their combustion as the more immediate cause. Humboldt maintained, on the authority of Ptolemy and some others of the ancients, that Sirius must in their time have been a red star, from the language in which they describe it, and that it must have subsequently, but prior to the time of Tycho Brahe, have become white or of its present colour. And certain stars are known to be at present changing their colour, among which η Argus may be specially mentioned, which, since 1843, when it had a reddish yellow or orange colour, was found in 1850 to have acquired a deep red colour, darker than the planet Mars. A double star in the Dolphin and one in the Lion, formerly noted by Herschel to be white, have also changed and become coloured binaries,—that of the Dolphin being golden yellow, with a bluish green companion, and that of the Lion a golden yellow, with a reddish green companion.

Another feature of these star systems is the inclination of their orbits to us, and their known variability. The orbits of Sirius, and many others of the binary stars, are so nearly of the proportions of planetary orbits in our own system, that their very slight ellipses would indicate them to be presented to our observation in a position perpendicular or transverse to our line of vision. Others of them are so extremely elliptical, that of Polaris, for example, exceeding in elongation any cometary orbit with which we are acquainted, that it may be suspected to be presented in a position diagonal or inclined to our line of vision, so that two sides of it suffer foreshortening to such a degree as to give it the appearance of a very long and narrow ellipse. We can conceive in like manner that many stars have the plane of their orbits so closely coinciding with our line of vision as to exhibit motion only in a very short straight line, between the two ends of which they seem to pendulate as if they were balanced by two equal impulses, which exactly compensated each other. One of the most interesting of these stars is Mira, or o Ceti, a star situated on the same parallel of latitude, about 50° westward from the lower star ζ in the belt of Orion. This star, which was the first discovered of its class, acquires at its maximum the brilliancy of a star of the second magnitude, from whence it decreases during about three months till it totally disappears. After remaining absent for about five months it reappears, and gradually recovers its brilliancy, till it acquires in about other three months its maximum brilliancy for the time, which is not always the same; and after reaching its maximum it again slowly diminishes in lustre, and disappears as before. Its period is 331·33 days, or somewhat less than eleven months, so that in eleven years it appears about twelve times at its maximum brightness. It has also the peculiarity of being a binary star, and were we able to discover it might be found to be ternary, and to have a third but dark central star round which it performs a small orbit, the dimensions of which from its distance we cannot detect—the diameter being so reduced by perspective. Of the many explanations given and attempted of this wonderful sideral phenomenon, none appears to harmonise so well with established astronomical analogy as this, that the plane of its orbit is in the line of our vision, and that the vanishing-point of this binary combination is at the distance of the semi-diameter of its orbit, which it cuts in two by a line transverse to the direction of our vision, so that one half of its orbit is within, and one half of it beyond the vanishing-point of the star. We can well enough conceive that in such circumstances a third star, as bright as Mira itself, might exist in the centre of such an orbit, forming the source of attraction, and yet be just beyond the vanishing-point, or exactly at that distance at which Mira itself disappears. Yet, it must not be omitted from consideration that Hind has called attention to other peculiarities of these variable stars, and has shown that the smaller ones are often of a reddish colour, and at their minimum appear to be surrounded with a dim atmosphere or fog. From this Arago has suggested that the diminution of brilliancy may be due to the interference of clouds intercepting their light, although this, it must be confessed, only removes the difficulty a step farther from intelligible explanation; for, as we have no experience of such clouds anywhere else in astronomy, we may well ask, Whence these clouds, and what are the causes of their periodicity?

The following are periodical stars, visible to the naked eye, and therefore capable of being watched by any observer, when once their positions are identified:—

		Period.	Change of Magnitude.	
		Days.	From	To
1	β Persei, or Algol	2·86	2½	4th
2	δ Cephei	5·36	2	3
3	η Aquilæ	7·17	3½	4½
4	β Lyræ	......	....	....
5	α Herculis	......	....	....
6	ο Ceti, or Mira	331·33	2	0
7	υ Hydræ	449·5	4	10
8	η Argus ....about	46 years.	1	4

The first five of the above are in northern constellations. The first, Algol, will be found to the west of Capella, and almost in a line with it (it is only about 4° farther to the south), and forming a triangle with Capella and the Pleiades. The second, δ Cephei, is in the head of that constellation, and on a line passing from the pointers onward, past Polaris to about 32° south of the pole. The third, η Aquilæ, is on a line passing from Castor and Pollux through the pole to about 90° south. The fourth, β Lyræ, is about 8° south, and slightly eastward of Vega; and the fifth, α Herculis, is about 30° south-west of Vega.

With regard to these star systems, it must be confessed that astronomy is at present in that state in which every fact and suggestion require to be imported and accumulated into a focus of induction sufficiently comprehensive to correct and establish the basis of future conclusions, and therefore it may not be uninteresting to consider a few of the questions which naturally arise and tend to throw light on this condition of the subject. Among them, one of considerable importance is how planets subordinate to a binary, ternary, or other multiple system, are regulated in their orbits, where the primaries or multiple suns of the system have a common centre of rotation, not resulting from any larger body placed there, but merely from the centre being that point of intermediate space where the balance of their respective gravitations and projectile forces meet and form an equipoise between them. It may well be asked, Do the planets of such a system revolve round the same point, or do they revolve round the respective suns of the systems, as moons and satellites do round our own planets, and many of them with possibly additional dependants in the form of satellites or moons to them? Unless the planets of such systems be very large bodies indeed, forming dark rivals in magnitude to the suns of their systems themselves, it is, perhaps, hardly possible that they can have their orbits formed round the common centre of motion. The probability rather is that where the planets are small, or have such a proportion in magnitude as that of the solar planets to their primary, they are subordinate to the several suns of the system, each system having, in all probability, a set of planets and satellites of its own. Though it is also highly probable that the orbits of such bodies are subject to much perturbation and many complications of motion, from the influence and attractive power of the other suns of the system. Including Vulcan, there may be said to be nine great planets belonging to our system, besides the planetoids, one hundred of which are already discovered, and many more still expected. But the proportion of the planets is as nothing compared with the comets connected with our system, nineteen of which have known elliptical orbits, connecting them permanently with our system, while thirty-seven have also elliptical orbits, which have not yet been so carefully noticed as to enable their dimensions to be given with precision. Besides these, 178 parabolic comets have been observed, and five comets with hyperbolic motions. The parabola and hyperbola are curves in conic sections which do not return into themselves so as to form elliptical or closed orbits. Of those comets, however, which are known to have elliptical orbits, and to be permanently connected with our system, and of which we shall have more to say in the proper place, many are of immense size, having prolongations or tails that occupy very extended and elongated areas of space. If, then, we are permitted to conceive that the suns of the multiple star systems are accompanied in anything like the same proportion as our own luminary with planets and comets, we must believe that there is frequently an amount of cometary vaporous matter interposed between them and us, which, though invisible when such suns are at their maximum brilliancy, may become apparent as a sort of cloud-like haze when the minimum light of the star is all that it has to contend with; because naturally the light of the star falling on the vaporous matter of comets intermediate between us and the star would illuminate that vapour with a luminosity nearer to us than the body of the star itself, and thereby create with its own rays on an intervening screen of vapour as it were a rival to the light of its own body. And hence, very possibly, the dim atmosphere or fog which Mr. Hind has observed when the variable stars are at their minimum visibility.

CHAPTER V.

Physical Structure of the Stars—Analogy from Terrestrial Chemistry—Distribution of Physical Elements—Fusion and Luminosity—Sustained Luminosity as in Solar Combustion—Photosphere, Ricegrains, etc.—Nature of Light—Its Manifestation—Misconceptions—Its Velocity—The Revision of the Subject—Electric Ocean of Space—Physical Composition of Comets perplexing to ordinary Chemical Laws.

Let us now endeavour to acquire for ourselves some adequate idea of the physical structure of the heavenly bodies, that we may be enabled to resume the subject we have just been dealing with, and carry our observations still farther, with the aid of additional and necessary elements of knowledge—required, not as means of investigation merely, but also as essential means of correct appreciation.

To commence with that which we are best assured of, the structure of our own world—we find by the aid of chemical science that it is composed of from sixty to seventy primary elements, three of which only are inherently gaseous, *i.e.*, oxygen, hydrogen, and nitrogen, while all the others are solids, and most of them capable of being reduced to metallic bases, and those of them not so reduced, such as carbon, sulphur, phosphorus, etc., suspected to be also reducible to metallic bases, though chemistry has not yet discovered the conditions and *modus operandi* under which their reduction may be accomplished. All eminent physicists now admit that our earth must have been at one time in a molten or fluid state from heat, and as all its known elements are capable of being reduced from the solid to the fluid state by heat, either separately or in combination with other solids, and also of being sublimated or reduced to the gaseous condition by an intense application of the same means, it is not difficult for the chemist to point to a temperature under which the whole solids of our world would be reduced to a state of perfect fusion and fluidity, or even raised to the universal condition of mere gas, with no more of body or solidity than is exhibited by the matter of comets, through the densest parts of which the faintest and most distant stars are distinctly seen. The existing aspect of our world however indicates that its highest temperature had not raised it to a state beyond the fusion of fluidity. In this condition we may suppose that its interior and denser elements occupied much of the condition which mingled metals exhibit in their compound form in a crucible over which the three external gases, oxygen, hydrogen, and nitrogen, constituting air and water, or at that higher temperature probably steam, floated as a cooling influence, acting on the surface of the molten nucleus, and forming, with certain of the elements for which they had greater affinity, that great granitic flux which seems to be recognized as the universal floor of the geologist, or the basis of the terrestrial crust which has become solidified and distributed into land. It is highly improbable, with the proportion of these three external gases known to prevail, that the earth ever was a blazing and luminous mass like the sun. The amount of hydrogen on its surface would prevent this, and keep down all but very partial volcanic and super-aqueous flame. The refrigeration of the granite flux or crust, under the persistent influence of the air and water formed from the several combinations of the three external gases simultaneously in all probability caused the granite envelope to contract around the interior and still molten nucleus of the terrestrial elements, and occasioned disruptions of the crust and ejections of the interior matter through them, such as the investigations of geology so very remarkably and corroboratively record. While the earth's crust must, from the effect of these eruptions and the action of the external gases upon them in forming compounds with the various elements ejected, have greatly increased in density and in variety of structure. Many speculations exist as to the thickness of the earth's crust, and the geologists have presented a singular array of conflicting views and theories on the subject, many of them not without some apparent scientific authority to support them, if, indeed, that can be called strictly scientific authority which leads to inconsistent and contradictory conclusions. Chemistry appears, singularly enough, to be the science least of all consulted by these theorists and speculators, and therefore its important resources are not made available in any of the explanations. To these resources we will now refer, for they are indispensable to the question. One of the first conditions which the laws of chemical science, supported by all chemical experience, would insist on is, that none of the three external gases could be in a state of combination with the interior elements of the world, while these were in a state of fusion; they must have then been, as they now are, external to the molten mass or nucleus. The temperature of fusion alone involves this as a chemical certainty. In the next place, assuming the internal elements to be in a state of fusion, there was nothing to cause them to cool down or solidify but the influence of the external gases acting upon the surface of the mass, and from the surface inwards. In the third place, that influence has evidently acted by first causing the formation of a granite flux, and afterwards other compounds, between the interior elements and the external gases, so that the nature of the earth's crust is in reality that of a series of compounds between the internal elements and the three external gases; except—and the exceptions are not extensive enough to form any considerable or appreciable portion of the solid matter considered as a crust—where in small quantities the interior elements have been ejected or deposited in comparative purity under a cooler temperature than that of their state of fusion within or beneath the crust. In the fourth place, it is not conceivable that the interior molten nucleus should have solidified as a homogeneous mass on the surface merely, without solidifying also to the centre; as the temperature of any molten homogeneous mass is always highest at the surface, from the universal tendency of high temperature to ascend: and the question chemistry suggests, therefore, as to the thickness of the earth's crust is, how far have the three external gases been able to penetrate and form compounds with the interior elements, and to form a compound crust around them? That they have been able to penetrate to the centre is a proposition which chemistry at once rejects as ridiculous and impossible. That they have been able to penetrate very deep, more than thirty miles or so, is in the highest degree improbable. So that by the correlation of this science to the subject we are reduced from extravagant speculation to very proximate limits in discussing this difficult question; limits as to which chemistry has a right to speak with the very highest authority, and to the exclusion of all speculation which does not take its laws and resources into account.

In whatever state of fluidity or fusion, therefore, the earth may originally have been, the three external gases preclude the possibility of its ever having been in such a state of luminosity as the sun; for though the atmosphere might well enough have supported that degree of combustion, the temperature implied must have elevated the whole water on the earth's surface to the condition of steam, which, interfusing itself through the atmosphere, must have destroyed its flame-supporting power. Looking, then, under the aid of analogy, from the chemistry of the earth to that of the sun, we are led to the conclusion that if the solar elements are the same, or similar to those of the earth, in all other respects, they are essentially different in the one particular of hydrogen gas, which either is not an element of the solar chemistry, or is so in so very diminished and feeble a proportion as to be incapable of interfering to any important extent with the condition of its atmosphere as a supporter of combustion; * and this may aid us a step in explaining the sustained power and continuity of solar light.

It is now placed beyond a doubt that the luminosity of the sun resides in the solar atmosphere, at a considerable elevation above the surface of its mass, and not in the solid matter of the luminary. This luminous region of the solar atmosphere is called the photosphere of the sun—from *photos*, light—and occupies one of three layers of atmosphere by which the solid matter of the sun is surrounded. The first layer, or stratum of atmosphere nearest to the body of the sphere, is comparatively dark or non-luminous. The second is the photosphere proper, or region of the intensely brilliant white light by which the solar system is illuminated; and the third stratum is comparatively non-luminous, like the first, save that the rose-tinted appearances seen during eclipses, above or external to the photosphere, are manifested in this third atmospheric stratum. Everything would appear to indicate that the atmosphere of the sun is filled with inflammable gas, given out from the solid matter of its body in sufficient quantities to be the means of maintaining continuous combustion in the region at which the photosphere is elevated above the surface of the solar sphere, and that the body of the sun is maintained in a state of continual fusion by the temperature of its interior elements, which the combustion of its exterior atmosphere and gases does not in any degree tend to reduce; so that so long as the temperature is maintained, or rather not interfered with by any refrigerating influence acting against the influences at present at work under the surface and above the surface of the solar sphere, there is nothing in the essential nature of its chemistry to prevent the great beacon of our system from burning on for ever, under a mere circulation, or analysis and synthesis of its elements; for as no portion of its chemistry can possibly be lost, or travel beyond the range of its own atmosphere, and as light is manifested both by the separation and the combination of chemical elements, there is nothing to prevent these inflammable gases from circulating in the atmosphere of the sun just as vapour does in our own atmosphere,—at one time floating as clouds, at another descending in rain, at a third rising into vapour by evaporation, again to form into clouds and again to descend in rain,—not an atom that rises going beyond the atmosphere of the world, and not an atom that falls going beyond the reach of the evaporation necessary to restore it to the atmosphere again. Such, then, may be said to be the resources and the nature of solar light, the dark stratum of lower atmosphere being in all probability in its upper part filled with that blue part of the light which any one who looks at a lighted candle will see prevails in the lower portion of a flame, nearest to the wick; while in the upper or third stratum, above the photosphere, those rose-coloured appearances may be only that reddish upper part of flame which a candle-light also so well exemplifies. The photosphere takes many appearances which coincide with what we might suppose to be extensive flames, under the influence of circulating currents in its atmospheric supporter of combustion—dividing itself into larger or smaller tongues of flame, according to the greater or less force or prevalence of the currents by which it may for the time be affected. These appearances are sometimes so minute that they have received various appellations, according to the taste of the observer, or the idea they thought themselves best capable of expressing by them—"granulations," "rice grains," "shingle beach," and "willow leaves," etc. The spots on the sun, which form an interesting study, also show that there are intervals of suspension in the combustion of certain points of his surface; for though the dark surface of the sun is seen through these openings, or spots, which are really blanks in the luminous photosphere, the sun's body is only comparatively dark in contrast with the intenser light of his own photosphere. Bouguer, who has made careful observations on this subject, informs us that, taking the light of the solar photosphere at 300,000 times that of the full moon, the dark nucleus of the sun, seen through these openings, possesses more than two thousand times the light of the full moon; so that the nucleus and the under stratum of the solar atmosphere are in all probability only *comparatively* dark.

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* A singular confirmation of this will hereafter appear, when we come to deal with the hydrogen line revealed by the solar spectrum.

But these investigations, while they reveal to us the mode in which solar light and combustion may be indefinitely maintained, only suggest another and profounder question, to which the mind of unsatisfied man will recur again and again; namely, What is light? It has been over and over again asserted by various independent thinkers, basing their deduction on the revelations of modern science, that light, heat, and electricity are all one and the same thing, in different states and circumstances of manifestation; and it may be said that the proof in support of this assertion is all but absolutely complete and conclusive. It is not so much a doubt that remains as a connecting link that is missing, which both parts of the chain its absence leaves disunited claim as inevitably intermediate, come when it will. All chemical elements contain electricity; all chemical elements are capable of emitting light and heat. In fusing elements and sublimating them, light and heat and electricity may be obtained from them. In reducing them to the solid state, in like manner, light and heat and electricity may be extracted from them. Whether, therefore, the direction be upward or downward in the scale of temperature, the same results may be obtained. This is no insignificant fact, as it shows that the manifestation of light, heat, and electricity is an inseparable characteristic of all chemical action; that, in fact, chemical action cannot take place without disturbing electricity, and along if not identical with it, disturbing light and heat also. It is true that in many cases the light and heat are latent; but the circumstances can always show reasons for this, without at all qualifying the truth of the general proposition; for the electricity can always be made to reveal both the light and the heat.

One phenomenon of electricity bearing directly on this subject, and very common and familiar in the experience of all who have observed the ordinary experiments with that fluid, is, that whenever a current of electricity is imperfectly interrupted, as for example by the two wires of a galvanic battery placed at a very short distance apart from each other, the electric current passes the intermediate space by the emission of a spark of light, which diffuses itself in every direction. There can be little doubt that this is the superfluous electricity, which cannot find its way through the non-conducting atmosphere, from the one wire to the other, taking the form of light to force its diffusion and equilibrium in every direction by means of universal radiation, or the dispersion of itself in the form of both light and heat. Indeed, there is no other mode in which imperfectly interrupted electricity can diffuse itself when impeded in its action; and the lightning flash is an example of this, as essentially as the electric spark. But it is one of the singular features of this phenomenon, that it never occurs save in a bad conducting or insulating medium, such as the atmosphere; and if light and electricity be really the same thing, we are compelled to infer from this circumstance that air is a great impediment to the diffusion and direct action of both electricity and light. Indeed, this may be proved by many familiar experiments; and one of the commonest known is that of a fiery ring, created by the motion of a piece of wood, with the end of it in a state of red heat, or the end of a red-hot poker. The completeness of this ring while the end of the stick or poker is only at one portion of the ring at any one time, is usually ascribed to the duration of images on the retina of the eye; but this is a fallacy, which the slightest testing will fully expose. If the person looking at the fiery ring should wink, however rapidly, he will always and instantaneously break the continuity of the ring by doing so, a proof that the ring itself has no permanent or complete impression on the retina, but that the completeness of the ring is entirely attributable to the slowness with which the atmosphere transmits the light to the eye. But another fact is, that the more intense the light the less easy we find it to make a complete ring with it at a slow rate of motion; a fact which makes it absolutely certain that intense light travels through an obstructing atmospheric medium more rapidly than a faint or weak light does; while it must be plain to the commonest apprehension that if the retaining power of the retina really were the cause of the completion of the fiery ring, such a peculiarity would be fatal to the known usefulness and quickness of the eye, in superseding one impression instantaneously by another in cases of sudden alarm or danger. At one period in the history of science it was generally believed that in free space light travelled instantaneously, for the very simple and apparently adequate reason that there was nothing to impede its transmission. It is to Römer's discussion of observations on the satellites of Jupiter, during the year 1675, that we owe the present invasion of that theory, and the now generally accepted doctrine that light is not transmitted instantaneously, but progressively, through free space. It had been found that the times calculated for the eclipses of Jupiter's satellites did not correspond with the observed times, and that when Jupiter was in perigee the eclipse always happened before the calculated time, while when in apogee it always occurred after it. As these were found regularly to be the result, Römer was induced to suspect that they were occasioned by the variations of Jupiter's distance from the earth; and that as this distance was greater or less, so the light took a longer or shorter time to travel from Jupiter to the earth. Guided by some information at his command, Römer assumed experimentally that light travelled at the rate of 192,000 miles per second; taking sixteen minutes and a half to travel a distance equal to the diameter of the earth's orbit; and making a trial of this hypothesis, he had the gratification to find his reasoning to be correct. Fizeau has since given the velocity of light as 2,000 miles per second more than Römer's estimate, or 194,000 miles per second. Although both of these are in excess of the fact by some thousands of miles per second, on their own data, in consequence of a reduction in the hitherto accepted value of the solar parallax, they are now the generally accepted rates of the velocity of light.

These calculations, however, had been received with great reluctance by the scientific world, and it is quite possible that the whole subject yet requires revision and reconsideration, as it is an important fact that the highest velocity given for light traversing free space, without making any allowance for its interruption by atmospheric media, is very much less than the velocity with which electricity travels through obstructing media; the velocity of electricity being at the rate of 288,000 miles per second in the circumstances under which Wheatstone's results were ascertained.

The accuracy of these electric facts is beyond a doubt; and if light and electricity be the same thing, it is scarcely possible to conceive that anything but a non-conducting or imperfectly conducting medium can impede its instantaneous action and transmission; while it is quite possible that the fainter light of Jupiter when at apogee, and its weaker power as compared with his stronger light when at perigee, may account for the whole retardation it experiences by ascribing it to the interruption of the terrestrial atmosphere alone. Science cannot well remain satisfied with this subject as it is; as so manifest a discrepancy as that between the velocity of light and the velocity of electricity must find an explanation somewhere, which Römer's and Fizeau's experiments do not as yet supply. It is quite certain that the atmosphere is one impeding medium, though Römer and Fizeau do not appear to have made any distinction on that account, while it is difficult to conceive that any impeding medium whatever exists in free space; and certainly the same amount of impediment cannot possibly exist in free space as that which is found to prevail in atmospheric media. It must also be kept in view that such a purely reflected light as that transmitted by Jupiter, may and must be very considerably weakened by the distance between his perigee and his apogee. Of course we are aware that the observations on the velocity of light do not depend on Jupiter alone, the transits of Venus and other data having also been employed; but it does not appear that in any of them the difference between free space and atmospheric media is duly eliminated, or that any of the calculations are perfect on that account alone.

The question may thus be said still to remain open—What is the velocity of light in free space, as compared with its velocity in atmospheric or other media? And the value of correlating electricity with astronomy in future observations on this subject is obviously of very great importance to the accuracy of the result; for no one science is entirely independent of other sciences in these times. From these considerations we refrain, in the present volume, from making any of those uses of the velocity of light as a standard of measurement or comparison, which is so common in astronomical works.

If it be true, as is generally suspected now, that the electric fluid pervades all known space, and forms an ocean between star system and star system in which the heavenly bodies float and move, it is not easy to conceive that anything affecting this electric and imponderable ocean should not instantaneously affect it from one end or extremity to the other; so that if light be really electricity in a state of universal radiation the rays should act on the great volume of surrounding electricity just as a push would do upon an iron rod suspended in space, by moving both ends of it in the given direction simultaneously. Had electricity the quality of ponderosity or gravitation, this might be objected to; but as it is imponderable, equilibrial in its diffusion, and incompressible, it is difficult to perceive or imagine any physical law or cause against its instantaneous submission to the action of light in free space; while the undulatory and progressive character of light viewed through the medium of an obstructing atmosphere, forms peculiarities attributable to its special circumstances in that medium which we find to be capable of impeding electricity as well as light.

Another and very peculiar feature of the physical structure of the heavenly bodies is that of the physics of comets. What the composition of the matter of comets is has long been a question of very great interest, and the more the subject is investigated the more difficult its solution appears. We have already made allusion to the earth and its elements, which chemistry has now very largely explained and dealt with. That cometary matter is vaporous is evident to all. The densest portions of it transmit the rays of stars through it without sensible obstruction. But, then, of what is the vapour composed? Can we suppose it to be of the same physical nature with any or all of the three external gases of our own world, or with any of the more solid elements of terrestrial chemistry, sublimated or expanded into the gaseous condition? We fear the answer of chemical science must be an emphatic negative, and from the following very obvious reasons: In the first place, cometary matter is subject to the law of solar attraction, but is not subject to the law of concentric attraction or gravitation within itself. It rarely takes the spherical form of concentric attraction, and even then it does not appear to do so as an indispensable condition of its own equilibrium. It quite as often takes eccentric and apparently capricious forms, totally at variance with every law of concentric attraction. It does not appear to possess even the law of adhesion or chemical affinity, as has been fully illustrated by the division of Biela's, otherwise called Gambart's, comet, in 1845, and several other well-authenticated instances of the same character. In the second place, were the matter of comets of the same nature with that of the three external gases of our world, it appears now to be perfectly certain that cometary matter has frequently come in contact with our atmosphere, as comets have certainly been observed to do more than once with the satellites and the body of Jupiter, and the result of such contact must have been to increase the volume of one or other or all of our external gases by a very appreciable degree. Let us suppose the cometary matter to be nitrogen; the proportion of our atmosphere and its health and life-sustaining power must obviously have been destroyed and poisoned by any considerable addition of nitrogen gas to its volume. If hydrogen, the aqueous vapour and water of the earth must have been sensibly increased. If oxygen, the atmospheric proportion must have been again disturbed; while, if a fair proportion of all three had been added, the weight of the atmosphere must have been increased as well as the volume of the water, and the general gravity and temperature of the world in some degree affected. Let us suppose it to be any gaseous form of some of the other terrestrial elements; here, in like manner, chemistry would lead us to expect condensation and precipitation of the elements, accompanied in all probability with a proportionately extended manifestation of combustion. But nothing of all these has ever been experienced by us from cometary proximity or contact; nor does cometary matter at all coincide in any of its manifestations with what we know of the physical matter of the world. What it is, therefore, is a mystery. We are led inevitably to suspect that it is composed of matter totally different from any with the chemical characteristics of which we are acquainted. Indeed, it would be a very great presumption on our part to assume that our terrestrial chemistry includes a portion of every physical element of the universe; and cometary matter manifestly claims exception to such a conclusion, and leaves our chemical laws adrift on an ocean of perplexity regarding it.

CHAPTER VI.

The Solar System as a part of the Galaxy—General Appearance of the Galaxy—Its Distance—Its Nearest Point—Its Size or Dimensions—A Minimum Estimate—Motion in certain Regions of it—Thinnest portion of the Galactic Ring—Brightest portion of it—Varied Aspects of it—Its general Course and Direction—Its general Density—Star Systems connected with the Galaxy.

We have already alluded to the sun's orbit round some great central point or influence, situated in the direction of the Pleiades,* and to the possibility that some immense body, with great powers of attraction, may be concealed there without our being ever able to detect its existence, or attain to more than a mere suspicion of its presence from the attractive power it exerts on and over our system; although it is necessary again to say that a central point of attraction, such as has been mentioned, does not necessarily involve the actual presence of any body whatever at that point. It has been already stated that two or more suns may balance each other in a binary or multiple system, by revolving round a central point where their forces meet, which may be intermediate between and external to both. But this subject receives altogether a higher and more extended interest, when we consider what Sir William Herschel long ago stated about the position of the solar system in that great belt or circle of stars which forms what is called the Galaxy, or Milky Way. The theory of Sir William is, that the sun occupies a position in this thick stratum of stars somewhere about the intersection of the lines in the following diagram near. to where the Milky Way divides into two streams. The consequence of such an arrangement and position would be, that in three directions an observer from the solar system would be able to look through or from the Milky Way with a thinner stratum of stars interposed between him and external space than when looking along the line of the Galaxy

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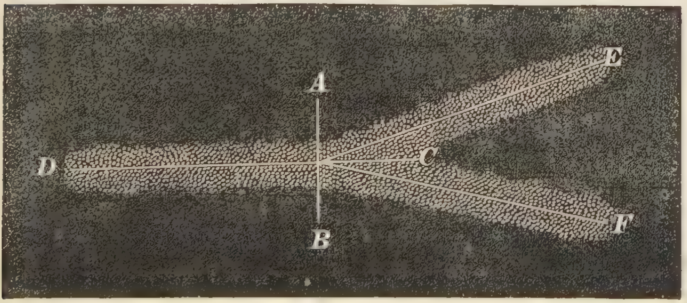
* The brightest star in the Pleiades is that indicated by Mädler as most nearly occupying the central position he has maintained in his recent revival of Wright's central-sun hypothesis; which was first started by the latter in 1750, though he cannot be regarded as absolutely the originator of this speculation.



The shortest direction of vision out of the Galaxy, to an observer on a body at the outer section would be in the transverse directions, A and B; and next to that in the direction of C; while in the directions D, E, F, the line of vision would be along the whole extended line of the continuous Galaxy. This theory of Sir William Herschel's has been found to have a general correspondence with the results of observation. But what it leads to is still more important; namely, that the sun, with his attendant secondaries and their satellites, is part of a great circle of stars which, to a distant view, may possibly present an appearance similar to the annular or ring nebula in Canes Venatici, given in the accompanying plate, or the nebula near γ Andromeda, when looked at under a foreshortening view; or possibly to some of the disc or planetary nebulæ given by Sir John Herschel, of which examples are also supplied in the illustration. Or its irregularities may even exhibit something of a spiral form, like that of the nebula between Ursa Majoris and Boötes, or that of Leonis or Pegasi, also in the illustration. In any case, it is probable that the Galaxy forms a self-balancing system, by the result of the mutual and combined attraction of all its parts meeting in a common centre, within its circumference somewhere, and not necessarily from the presence of any one great central body powerful enough to retain its various surrounding elements and their systems in position or orbitual dependence by the force of its universally exerted attraction. How far this common centre is in the region or direction of the Pleiades, or at η Tauri, otherwise called Alcyone, of that group, as maintained by Mädler, is a question which has yet to be determined. The Pleiades certainly do not appear to us to be in the same plane with the great circle of the Galaxy, but the divergence from that plane is not so great as to prevent its appearance being attributable rather to that of the solar system, in reference to the centre of the plane, than to any actual eccentricity in the Pleiades. Thus, were the sun's position nearer to the one side of the star zone than to the other, objects in the centre of the plane would appear from our point of view as if situated beyond it on the other side, and it is quite possible that the many apparent irregularities in the aspect of the Milky Way may be occasioned by our position not being in the central plane of the zone.

The result of Sir William Herschel's investigations, fully confirmed by subsequent observation, is, that the Galaxy, or Milky Way, forms the nearest nebulous appearance to our system.[*] In fact, our solar system forms a portion of that great nebulous ring, the north pole of which is situated near to the constellation known as Coma Berenices, and the south pole in Cetus. When examined by powerful telescopes, the Milky Way is found to consist of immense irregularly distributed star clusters. Sir William Herschel, in a contribution to the *Philosophical Transactions* of 1785, estimated, in viewing the Galaxy, that 116,000 passed through the field of his telescope in a quarter of an hour. Subsequent observations have given results still more astonishing. Sir John Herschel computed that an 18-inch reflector contained, probably, many more than five and a quarter millions of stars: and Struve considered that the 20-feet reflector of Sir William Herschel contained as many as twenty millions and a half. Yet dense as these congregations of stars are, the Milky Way has been penetrated at many points by the space-piercing power of optics, and so entirely resolved into individual stars that the clear non-luminous background is seen beyond them. At other points, the highest optical power has only revealed behind the stars a pale luminosity, showing the Galaxy to be utterly impenetrable in that direction.

There are, however, many dark portions of this star zone where it has been found impossible to perceive any star, even of the twentieth magnitude; for the continuity of the Galaxy is broken at certain points, and subsequently resumed. Thus there is a wide break at λ and γ Argûs, and another occurs at ε Cygni. Throughout the portion of it which traverses the southern hemisphere, and as it approaches its nearest point to the south celestial pole, the striking brightness of the Milky Way becomes so conspicuous, as compared with its luminosity at other points, that a decided impression of our greater nearness to it in that direction is treated; and, singularly enough, this region coincides with that of α Centauri, the nearest fixed star, which we have already more than once had occasion to mention. But besides the gaps in it already referred to, the Milky Way has apparent openings, apertures, or blank spaces, as they may be called, in a large portion of which few or no stars are visible. This is peculiarly the case at a point below and to the left of the Southern Cross, which has received from the early southern voyagers the names of the Coal Sack, or the Hole in the Sky—a pear-shaped vacancy of about 8° in length by 5° in breadth, and in which only one small star is visible to the unaided eye. This space has an appearance of blankness from the want of all nebulous luminosity within it, as compared with the remarkably bright margin, composed of the brightest portion of the Milky Way, by which it is enclosed or bounded. A dark space not altogether unlike it also occurs in the northern hemisphere, in the constellation Cygni, between the stars α, ε, and γ of that constellation; but the brightness of the surrounding portion of the Galaxy is not there so great, so that the darkness of this space is not rendered quite so conspicuous by contrast.

Of the immense magnitude and extent of the Milky Way, Sir William Herschel has supplied some idea by the calculations he made of the penetrating powers of his great telescope. From examination he found that in some directions he could not with his greatest power reach the limits of the Galaxy, though he calculated that he had penetrated with it depths of space occupied by stars at a distance of more than 2,300 times the mean distance of first-magnitude stars. To give the reader some idea of this, let us endeavour to bring together a few standards of comparison as aids to the mind. The mean distance of Sirius and Capella, stars of the first magnitude, is about 278,203,000,000,000 miles. Sir Wm. Herschel must, therefore, have penetrated a region more than 639,866,900,000,000,000 miles distant before he reached that part of the Galaxy where he found his view still opposed to a pale background of luminous, irresolvable nebulosity, utterly unfathomable by his optical powers. He found also that the Milky Way visibly increased in dimensions in many directions as higher optical power was applied to its examination; so that very much of it is beyond the range of the naked eye. Taking such a distance as we have just mentioned as the mean distance of the Milky Way, we should have a ring or zone of stars 1,279,733,800,000,000,000 miles in diameter, or about 4,479,068,300,000,000,000 in circumference—and we may safely take this as a minimum—*it cannot be less!* Indeed, the calculation from the density of the resolvable star strata already mentioned, assuming the stars to be the minimum distance between star and star of α Centauri from the sun, would give a diameter and circumference immensely greater. A body at this distance, with the apparent diameter of 30′, or half a degree (about that of the moon's disc), would have a diameter in reality of about 6,221,000,000,000,000 miles, and would fill a spherical area of space more than fourteen times the distance of Capella in diameter, and of which space the sun, with his planets and comets, assuming his spherical area of attraction to be about one-twentieth part of the distance to α Centauri in diameter as before assumed, or 1,000,000,000,000 miles, would occupy only about the 240,000,000,000th part. We may well, therefore, feel satisfied that stars, it may be thousands of times the magnitude of our sun, are less conspicuous here than the very small dust in the balance, and have their light mingled and blended together in a gleam more feeble than the faintest phosphorescence which is rendered visible by the intensity of night.

At such a distance realities become phantoms, and systems massive and grand enough to overwhelm us with the stupendous incomprehensibility of their great Creator's power, fade into ghost-like and spectral images on the far margin of failing visibility, haunting the mighty confine with dreamy and shadowy outlines which imagination conjures with, and which often, in the accidental appearance their optical distance gives them, startle and surprise even fancy itself. The reader has only to turn to our plates, and explanations of the nebulæ, more fully to appreciate this.

At such a distance as that of the Galaxy, on the minimum already stated, a star travelling through space at the rate of ten thousand miles per hour would take more than six hundred millions of years to travel a distance which, to an observer in the centre of the ring, would appear no larger than one-thousandth part of the apparent diameter of the moon. Were the speed ten times as great, or at the rate of one hundred thousand miles per hour, the whole length it would have travelled from the creation of the world to the present time would not, to the eye of an observer gifted with power to watch it for the whole period, afford an appreciable distance or perceptible motion. And yet motion has been observed in the Galaxy within a thousandth part of that period. On what scale does it proceed? At what enormous and overwhelming speed? Are there bodies that move at more than the rate of a hundred million miles per hour through the vast regions of the infinite? If so, what mighty attraction balances and reins them, like a finely-handled war horse, in their orbits, and checks and curbs with its master power the space-plunging impetuosity of their fiery race? Such furious rapidity must surely burst all ordinary bondage, snap and break all common fettering, and yield homage to none but an *Omnipotent* hand. Here surely illimitable and absolute Deity alone can reign! Certain it is, that Sir William Herschel was enabled to put upon undisputed record the fact, that the Galaxy was *widening* at the point where it branches out into two strata, and near to which division our system is situated. By what motion, whether of our system or of the Galaxy itself, or reciprocably of both, this fact is revealed, is a question which science has not as yet satisfactorily grappled with, if it will ever be able successfully to do so; if, indeed, mystery to man be not for ever written over the phenomenon by the very majesty and vastness of the subject.

Near the constellation of the Unicorn, and in that of Perseus, the Milky Way exhibits its minimum luminosity; and here at a point in the sword hilt of Perseus Sir William Herschel's most interesting penetration of the zone was made. To the naked eye not a star is visible; but with a small telescopic power numerous stars burst like creations from the vacuity of space; and with increased optical aid bright spots and nebulous haze bring up the distant rear, and surprise us at the feebleness of natural vision. When Sir William Herschel brought his great telescope to bear upon this region, a countless multitude of magnificent suns or star systems greeted his gaze with their brilliant and sparkling light; and clear, through and beyond all, the mighty instrument penetrated into the solemn and sable background of night, unspotted by a single nebula, unmitigated in its deep intensity by a single luminosity unresolved. In penetrating this distance he considered that he had passed through a stratum of more than five hundred suns, ranged in perspective one behind the other, at distances each from each not less than that of the nearest fixed star from the sun. What idea does this give us of the thickness of the Milky Way even in its thinnest part! Five hundred times the distance of α Centauri is 10,504,000,000,000,000, or about a sixtieth part of what we before intimated as the minimum of the Galaxy's distance from us. So that the semi-diameter or distance of this ring to its centre would only be, after all, sixty times greater than its thickness, or the depth of its stratum of stars at its thinnest and least luminous point. Such a fact will show the previous estimate of its distance to be moderate, and in all probability very far within the truth; for let it be remembered, at the same time, that the nearest star of this stratum in the sword hilt of Perseus is so distant from us as to be entirely invisible to the naked eye. What in comparison must the thickness of the Milky Way be in other regions, where the mightiest instruments since added to the triumphs of optical achievement fail to penetrate the depth of that profound and ever-receding lustre which displaces with the remotest noonday splendour of myriads on myriads of suns the dark frowning solitudes and vacuities of interminable space! Here a stratum of 500 star systems in depth would be lost like so many atoms of sand on the immensity of an ocean shore. They might be blotted out, and the most careful observer, with the finest instrument, would not miss them. They might be rekindled, and all their sunbursts united would not add an appreciable glimmer to the pale lustre of the steadfast background. Truly, here is a step in infinitude —a fragment of the eternity of space and power!

The brightest part of the Milky Way is that in the southern hemisphere, between the constellations of the Altar and Argo, which is much more remarkable than that bright portion in the northern hemisphere, extending over Aquila and Cygnus; and this has led to the suspicion already mentioned, that we are nearer to that part of it which traverses the southern region of the heavens. This suspicion is much confirmed by the fact, that a line of brilliant stars passes from Sirius over Argo, the Southern Cross, the Centaur, and the Scorpion, in a luminous and conspicuous zone of such clear and decided lustre that its rising above the horizon is preceded by an illumination of the heavens, which Captain Jacob has likened to that of the light of new moon. This remarkable zone of detached stars, which doubtless would blend their light with that of the Galaxy were we at a greater distance, appears to indicate that we are near enough to the Milky Way at this point to be able to see the stars of which it is composed more distinctively and extensively detached from each other, or more continuously resolved, if we may so express it, from the general zone than they are at any other part of it.

Altogether the varied aspects and characteristics of the Galaxy are rich in interest and wonder, and full of features of singular beauty and peculiarly majestic immensity; and, though much attention has been bestowed upon it by the most eminent astronomers of all ages, its vast resources of ever-increasing novelty, as enlarged optical power is applied to it, show that it is far from exhausted as a subject of study, if indeed it be not better and more modest to say, that with all we know of it, it is still very little understood. The main-line of this magnificent star zone is very nearly that of a circle surrounding us in one grand and comprehensive sweep, and many of its irregularities may possibly admit of being accounted for as deviations from this general or prevailing form, by the fact of our being perhaps a little to one side of the zone, though nearly in the centre of its breadth, and that we may not therefore be in the position necessary to obtain the most symmetrical view of it. It is inclined at an angle to the equinoxial plane of, approximately, 63°, and throughout nearly one half of its entire extent it is divided into two great or principal branches. In the northern hemisphere it passes in two branches from Serpens on the south, near the equator, northward over Aquila, Cygnus, Cassiopeia, Perseus, and the lower part of Auriga, through the shoulder of Monoceros; and in the southern hemisphere it continues from Monoceros to Argo, and thence to the Southern Cross, below and to the left of which the coal sack or hole in the sky, before mentioned, is formed by an intense blank at the brightest point of its luminosity; hence it proceeds onward over the fore-feet of the Centaur a little to the north of α Centauri, and thence, with a division into two branches, over Lupus, the Altar, Scorpion, and Sagittarius, to the point at Serpens, from which we set out. Its main division into two branches extends from near *a* Centauri, in the southern hemisphere, to Cygnus in the north. Numerous branches are thrown off at various points. From Cassiopeia one branch proceeds towards *a* Persei, and onward beyond till it is lost in the direction of the Hyades and Pleiades. Another, and a very considerable branch, passes off from Cepheus towards the pole. At many points its breadth is very great, at others of extreme tenuity, and its general aspect throughout its course is that of great irregularity and inequality. Between the two great branches several cross bars or star bridges occur, which span the distance between them. Of course, as has been already indicated, there are numerous points in this wonderful system, where the highest telescopic power has failed to penetrate the nebulous background, standing beyond the thick dense stratum of intervening stars, by which the nearer portions of the zone are rendered so brilliant and luminous to the unaided eye, so that the Milky Way has many magnificent and peculiar nebulæ of its own. These nebulæ, however, have not received that attention which they deserve, nor have they generally been so carefully evolved or so completely distinguished from the general zone with which they appear to be connected, as it is to be hoped they yet and very soon will be. The inexhaustible immensity of astronomical objects has of late divided all the scientific ability at command in so many other directions, that numerous as are the distinguished astronomers of the time, and great as their labours and achievements have been, the field of science still wants recruits to swell the ranks of active investigation, and supply the demands for fuller information about many neglected regions of the space which optical skill has subjected to our search.

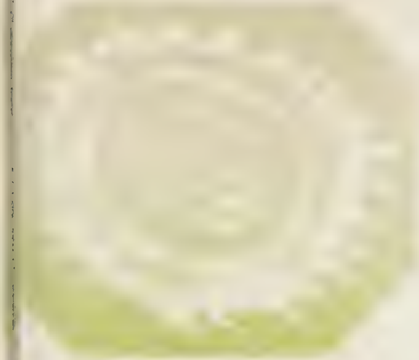
We have seen, from a preceding explanation, that the thinnest part of the Milky Way is about one-sixtieth part of its semi-diameter, so that from the centre of the ring to its outer circumference here is probably about sixty-one times its thickness at this extremely attenuated point. The extreme thickness of the ring at its maximum points must be immensely greater than this, extending both inward nearer to the centre, and outward beyond the average circumference; for at the thin point mentioned it has been explained that there are no stars visible to the naked eye in the foreground, and no irresolvable nebulæ in the background. Ten times the thickness of this thin stratum of telescopic stars, therefore, is more likely to be an approximation to the general depth and density of the ring, in which case the interior or central space within the ring would be only as twelve times its general outward breadth. How far this would appear an entirely open and vacant space within the ring, to a distant view, it is somewhat difficult to say. The solitary, binary, and other multiple star systems all around us probably belong to it, as well as our own solar system, and their scattered and separated appearance may all be due to the peculiarity merely of our eccentric point of view. If this be so, they might be found, from a very distant observation, to blend so in with the general system of the Galaxy as to fill up, in a very great measure, the interior and, to us, apparently void space comprehended by the great star zone, giving it considerably more appearance of central condensation than we might otherwise suppose, and realizing much more of the form of a disc than that merely of a ring. The probability of all the scattered and apparently isolated star systems around us being connected with it, will receive much strength from facts and phenomena of a very remarkable character, which we shall have to deal with in the immediately succeeding chapters, in which we will now proceed to introduce the reader to the various nebulæ which the improvements of the telescope, in the hands of the late Earl Rosse and others, have recently added to the records of astronomical discovery.

CHAPTER VII.

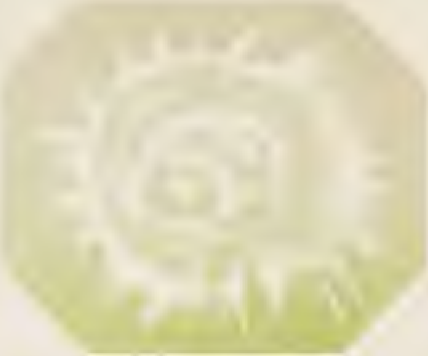
The Annular, Disc, and Spiral Nebulæ—The portions of the Heavens occupied by them—Their wide separation from the Galaxy in the direction of its poles—Classification and characteristics of the Nebulæ—Other Galaxies—Nebula 97 M Ursæ Majoris—Comparison with our Galaxy—Its distance, etc.—57 M Lyræ—Some prevailing characteristics of the Nebulæ—Humboldt and increased resolving power—Spiral Nebulæ—Nebulous Stars.

In the preceding chapter an endeavour has been made to give a pretty minute as well as comprehensive explanation of the Galaxy, or Milky Way; its structure, shape, dimensions, and other peculiarities. It has also been mentioned that it has at many points irresolvable and nebulous backgrounds, as yet too profoundly distant for the penetration of the telescope. These, however, are not the regions of the nebulæ proper with which we are now about to deal, and which have formed the great subjects of recent astronomical attention and discovery. These nebulæ are altogether independent of and widely separated from every part of it. Indeed, their greatest accumulation lies towards the extreme ends of a line passing through the centre of the galactic ring, and forming the axis by which it would be balanced and on which it revolves, if we are correct in suspecting that it is self-balancing and has a motion round its own centre. An observer looking through the centre of the ring of the Milky Way, therefore, in one direction, would find in the region of Coma Berenices, in which the north pole of the Milky Way is situated, the greatest accu-

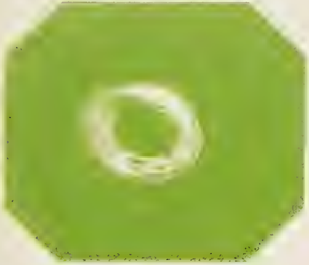
Plate V. ANNULAR PLANETARY & SPIRAL NEBULÆ



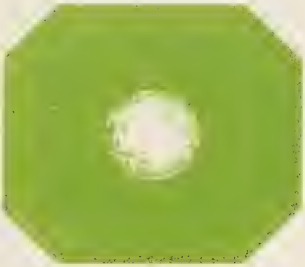
57 M. Lyræ.
E. of Rosse.



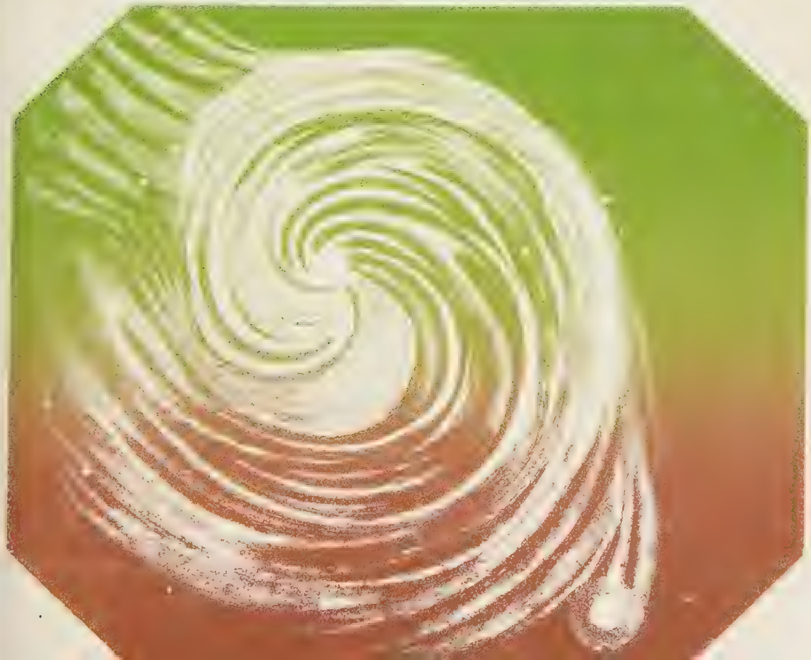
97 M. Ursæ Majoris
E. of Rosse.



57 M. Lyræ (less resolved)
J. Herschel.



97 M. Ursæ Majoris (less resolved)
Sir J. Herschel



mulation of nebulæ at the northern side of the galactic ring in that constellation, and the adjacent ones of Leo, Virgo, Canes Venatici, Boötes, Draco, Ursæ Majoris, Camelopardalus; while towards the south pole of the Milky Way, in the constellation of Cetus, they extend from Pisces and Pegasus to Andromeda; the richest regions of nebulæ being those furthest from the Milky Way, and extending nearest to the poles of its axis. Nothing can show the total separation and independence of these nebulæ in regard to the Milky Way more completely than these two opposite directions in which they lie. In all other directions, indeed, we may be said to have our view bounded or obstructed by the great zone of the Galaxy. In these two directions we look as absolutely away from it, and from all the plane of it, as it is possible to conceive, and we may conclude that they are as widely distant from the Galaxy, therefore, as the highest power of the telescope will allow us to penetrate and recognize them.

While many star clusters are visible to the naked eye, such as the Pleiades, Hyades, Tarus, etc., these cannot be called nebulous in the strict sense of the word, as they are never, even to the unaided vision, blended or confused together; and, indeed, clusters easily resolvable into distinct stars by ordinary telescopes can hardly now claim the distinctive appellation of nebulæ proper. It is where the higher powers of the telescope are tasked in their resolution that they are really nebulous in their prevailing appearance, and now entitled to be ranked as such. Of these there are two classes having great regularity of form, and an apparent conformity to the conditions of mutual attraction or gravitation, which give them rank as more intelligible in their arrangement than others. These are—

I. Annular Nebulæ (Circular and Elliptical).

II. Planetary or Disc Nebulæ (Circular and Elliptical).

There are three others, some of the peculiarities of which render them less intelligible, though in some exceptional instances they do not differ so widely from the first two classes as they generally do. They may be stated in the order of—

III. Nebulous Stars.

IV. Spiral Nebulæ, and

V. Irregular Nebulæ.

Of the first of the above classes 57 M Lyræ, 4290 H. Scorpii, 11 ♅ IV. of the same constellation, and 13 ♅ IV. Cygni, are the finest specimens of the circular or nearly circular form; while that near γ Andromedæ and 4058 II Draconis may be considered, from angularity of view and foreshortening, to be apparently elliptical specimens of the same class.

Of the second class originally, or, perhaps, thought to belong partially to both the first and the second, until further developed into a spiral nebula of the fourth class, might be taken the fine annular and planetary nebula, 51 M Canum Venaticorum, as given by Sir J. Herschel. Other specimens of the same class, disc shaped as well as elliptical (also from foreshortening, in all probability), are given in the plates. A very fine, but, at the same time, most singular specimen is 97 M Ursæ Majoris, as resolved by Earl Rosse.

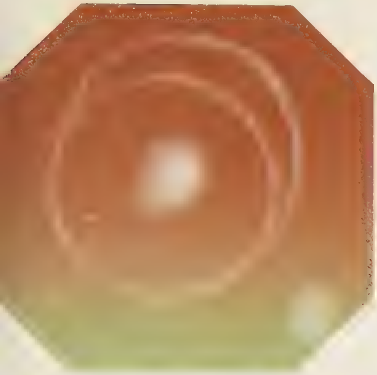
Of the third class, or nebulous stars, Earl Rosse has given fine examples from Argo, ι Orionus, and Gemini. Of the fourth class, or spiral nebulæ, H Leonis, 99 M Virginis, 4892 H Pegasi, and 51 M Canum Venaticorum (already referred to under the second class), are striking specimens, as developed by Earl Rosse.

The fifth class we shall in the meantime reserve for further and separate consideration.

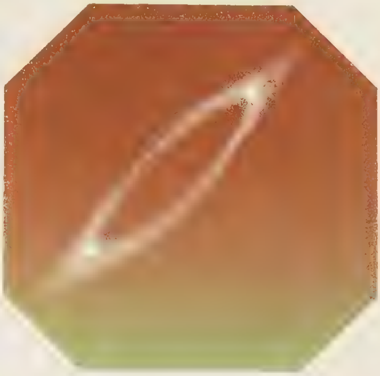
Let us now proceed, if we can, by the aid of any means or standard, to realize some idea of the immensity of the subject we are dealing with; for these nebulæ are more than mere pictures of capricious and eccentric form and outline,

Plate VI.

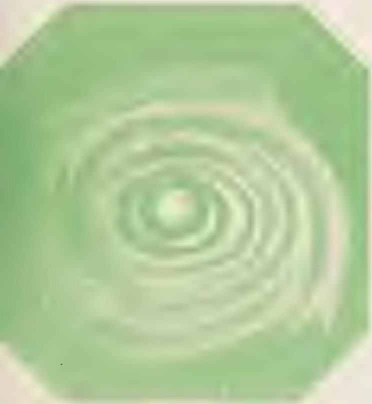
NEBULÆ OF GALACTIC FORMS



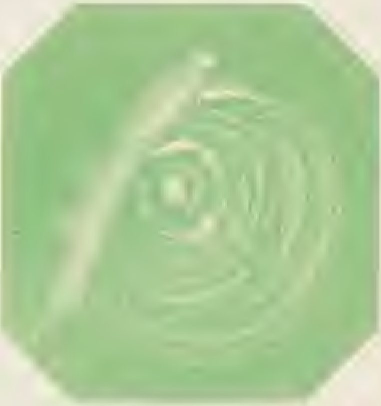
Nebula in Canes Venatici.



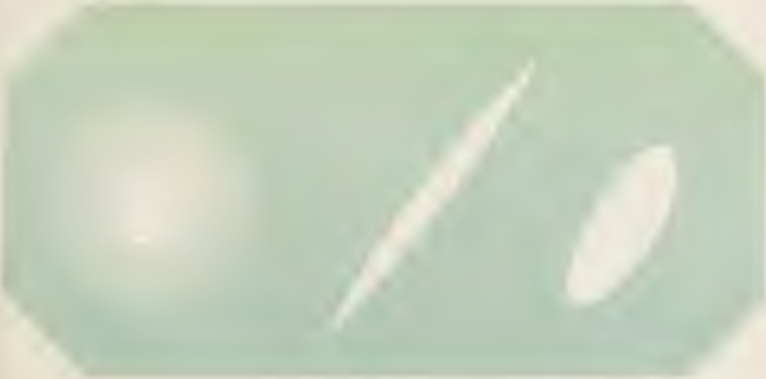
Nebula near Andromeda



Spiral Nebula H. Leonis.



Spiral Nebula 4892 H. Pegasi.



Circular and Elliptical Disc or Planetary Nebulæ

Examples of Annular, Spiral and Planetary Nebulæ

studding the distant dimness of half-vanished starlight with grotesque faces and shadowy details. One of the largest, and presumably therefore the nearest, of the nebulæ of the second class, or planetary nebulæ, is situated in the constellation Ursæ Majoris, and was discovered by Méchain in 1781. The diameter of its disc is 2′40″. Have we any means of approximating its real dimensions from this meagre detail, and thereby its probable distance? A diameter of 2′40″ is about one-twelfth part of the apparent diameter of the moon; but we are little the better for knowing that this nebula would only appear about a hundred and forty-fourth part of the size of the moon's disc, in consequence of its distance. May we assume its real diameter, not its apparent one, to be as great as that of the great ring of the Galaxy—why not? It is evidently, if Earl Rosse's development be correct, a system as complete as complicated, and as peculiar in all respects as the Milky Way, for though called still a planetary nebula, it is a very complex and compound ring nebula indeed, more so by many degrees than we know or can as yet justifiably either suspect or imagine our own Galaxy to be. It is, in fact, the planetary nebula, 97 M Ursæ Majoris, of which we have already given, on the authority of Earl Rosse, that strange presentment so like a halo-surrounded star-eyed skull, a death's head lit by glowworms peering from its ghastly sockets, and circled with a rayed ring of glory, which might pass in its severe simplicity for the serrated rim of an old Spartan crown; or that other jagged and spike-wreathed chaplet, worn by the King Imperial for us all. In all respects that nebula claims equality with the Galaxy in nice and minutely detailed complexity. The probability of its full equality in size, therefore, cannot be justifiably evaded, if analogy, our only guide in those far depths of infinitude, be taken as the basis of any speculation on the subject. Let us see, then, what such a diameter as that of the Galaxy would give for its actual distance. We stated the probable minimum diameter of the Galaxy before, with some authority to guide and sanction us, at 1,279,733,800,000,000,000 miles; and though we saw some reason for rather increasing that estimate on further consideration of the subject, we will not now enlarge the figures already given, but be content with them as they are, for such a diameter would give us the distance of the planetary nebula, 97 M Ursæ Majoris, as 1,580,000,000,000,000,000,000 miles, a sum immense enough to comprehend, being more than one thousand two hundred times the diameter of the great zone of the Galaxy itself. Is this, then, really the nearest of the nebulæ on an equally grand scale with the Milky Way? And do these mighty and complicated systems, with their united forces, require such immense spaces of separation to have adequate and undisturbed areas of attraction for their combined and accumulated gravitation? Who can inform us why space is so prodigally assigned and parcelled out to them else, while stars and systems seem to be huddled and piled on each other in the crowding distance, as if they elbowed for room, and had to struggle for individual existence in a seething and suffocating crowd? What is the distance of Capella, the furthest measured of the fixed stars, as matter of standard and comparison here! Alas! three million seven hundred thousand times the distance of Capella would not reach the region of this second Galaxy—this nebulous 97 M Ursæ Majoris!

What, then, are we to say or surmise of other nebulæ still more distant? There is but one mode of possible measurement—by approximation and analogy—open to us here; and it is from the external fact inwardly; for we are far out beyond any possible measurement from the greatest base available to man as a practical unit of remote mensuration. The circle of the whole heavens, even at the immense distance we have allowed in the preceding estimate, would not hold in line more than five thousand nebulæ of the diameter of the Milky Way, or of 97 M Ursæ Majoris just assumed; but many more than five thousand of these nebulæ, of various forms, according to the different classes we have already stated, are already known, and they do not occupy anything like that proportion of apparent space which we have just indicated. In the two Magellanic Clouds, or Nubeculæ, alone, Sir John Herschel found 328 nebulæ—291 in the major and 37 in the minor nubecula, besides numerous star clusters and single stars.

That our estimate of the density of the great star zone of the Galaxy is not excessive, as matter of analogy, when compared with other annular nebulæ of the first class, may be shown by a reference to the annular nebula 57 M Lyræ. In this instance, the central vacuity is little more, as Sir John Herschel has remarked, than one half of the entire diameter of the ring. Assuming the ring nebulæ, also on the basis of analogy, to be as great in all other respects as the Galaxy, the depth of the star stratum of the ring, from its interior outwards, would be about 600,000,000,000,000,000 miles, and assuming its width in the line of its axis, or its breadth of rim, to be the same, there would be in this space, cutting the ring rim in transverse section, room for about 800,000,000 stars, each of the minimum size and distance from the others of α Centauri from the sun. This is what would be revealed, in all probability, by a single layer of stars occupying the transverse section of one part only of the hoop of this mighty ring. What can we say, then, as to the combined and accumulated number of stars required to make up the whole ring, and give it that dense and irresolvable nebulous appearance which it presents in all telescopes up to the power of Herschel's great instrument? The telescope of Earl Rosse resolves this annulus into extremely minute stars, as shown in the diagram of it, with an adhesion of stars serrating its external edges; and striæ, or bands of stars in straight line, passing across its interior opening, like the strings or chords of a lyre; a singular but purely factitious coincidence with the name of the constellation to which it belongs. If our estimate of this annulus be approximately correct, the telescopic power of Lord Rosse's great reflector must here pass through a stratum of about twenty-eight thousand stars in line before penetrating to the dark background of space beyond them; but quite probably the breadth of the rim is not so great as its depth. Indeed, for reasons which will immediately appear, this is not likely in any instance of annular or planetary nebulæ, although it must still be remembered that the Milky Way does show an extraordinary breadth as well as depth in many places, and that very considerable breadth is characteristic of all examples, though it will be found that they are limited to a proportion pretty closely adhered to as a general rule—so prevalent and unexceptional, indeed, as to be remarkable, and to indicate a special coincidence with known laws, amounting to sufficient conformity to justify an inference as to the physical conditions of these discs and annuli, and the mutual relations and dependence of their parts. It must be also remembered what we have found in the case of Sirius, with regard to comparatively dark companion stars, not of the nature of planetary dependants, but as rivals in gravitation and magnitude. Here, doubtless, in these distant annuli, many such feebly lit bodies may be interspersed throughout the dense stratum of the rings and discs, impeding the telescopic penetration of them with a rayless but at the same time physical solidity—indistinguishable from the night-like background of starless infinitude beyond. And if the proportion of planets, planetoids, and satellites, with cometary dependants, bears anything like the same ratio to these distant suns that we find prevailing in our

Crab Nebula in Taurus

Spiral Nebula 99 M Virginis

Nebula in Argo

Nebula in the Unicorn

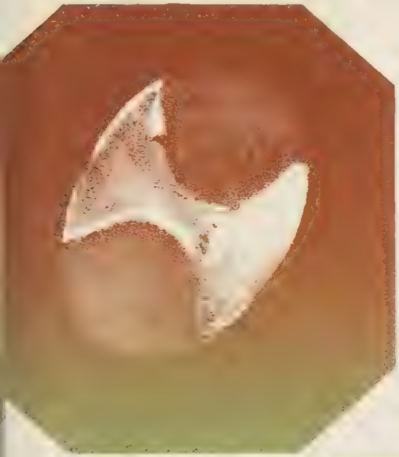
own solar system, the physical constitution of such annuli or discs must be a very dense and complex compound of chemical matter and physical arrangement indeed.

But let us here endeavour to ascertain how far it is possible to educe any general law from the special aspects of these nebulæ of the first and second class to aid our appreciation of them, in their prevailing appearance and uniformity. Now, it is a very singular and significant fact, that whenever any of these nebulæ have their edges turned in our direction, they present an extremely elongated elliptical form, showing that the disc or ring lies in a comparatively flat plane, and is not of a globular or spherical character. What does this imply, if it be not a conformity to the physical conditions under which mutual balancing and revolution round a common centre or axis of rotation alone are possible? A spherical arrangement of equal diameter in all directions would be a perplexity, for the component stars could not possibly have an axis of rotation passing through one part of their common diameter more absolutely than through another; and they could not have a mere centre of rotation in their common centre without leading to endless collision, derangement, and confusion. But all the parts of a ring or flattened disc may be self-balancing on a common axis of rotation, and may revolve round it without occasioning more serious perturbations to each other than are found to prevail, without the slightest practical derangement, among the planets, etc., of the solar system. It is true, that we do not observe motion in these distant discs and rings; but if we find a strict and uniform compliance with the conditions on which alone motion is possible and liability to confusion and derangement absolutely excluded, with what a mighty stride are we enabled to approach every thing we can reasonably require from the all but utterly incomprehensible immensity of the subject. At the distance of such objects, a being with the longevity of Methuselah might sit on a poor clay atom of a world, from florid boyhood till the hoary crown of years fell from his bleached and furrowed brow; nay, his unsatisfied ghost might haunt the scene for a million of years afterwards without being able, from first to last of the vast period, to discover appreciable motion in these remote and isolated universes of matter, though all the while they might be travelling at the rate of no less than ten thousand miles per hour, in their myriad orbits round their polar line. What a region of space there is presented here! and yet what a mere fragment manifestly of that boundless region called infinitude, of whose unfathomable depths and immensities we see appreciable and demonstrated portions, of still greater magnitude, on every side all around them! and whose outward and expanding areas are capable of accommodating, and in all probability do accommodate, had we the optical power to explore them, system after system of these nebulæ, ranged in as dense accumulation through the interminable perspective as the stars in the thickest stratum of the yet impenetrable Galaxy!

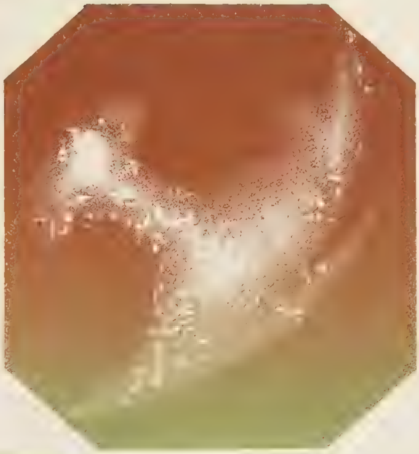
Humboldt has put the proposition: "By increasing optical power, resolution of old and discovery of new nebulæ would follow each other in endless succession; so that it may be fairly asked whether we can, with probability, assume both such a state of the universe, and such a degree of improvement in optical instruments, that in the whole firmament there shall not remain one unresolved nebula?" The question may well be put; but the answer is, that it is just as impossible to assume or conceive such a condition of the universe, as to conceive a limit to infinitude, and explain the nature of that limit; or a limit to that power which can so visibly traverse and fill it with interminable star systems and nebulous combinations, and regulate, balance, and control them all.

e VII.

"DUMB BELL" NEBULA IN VULPECULA

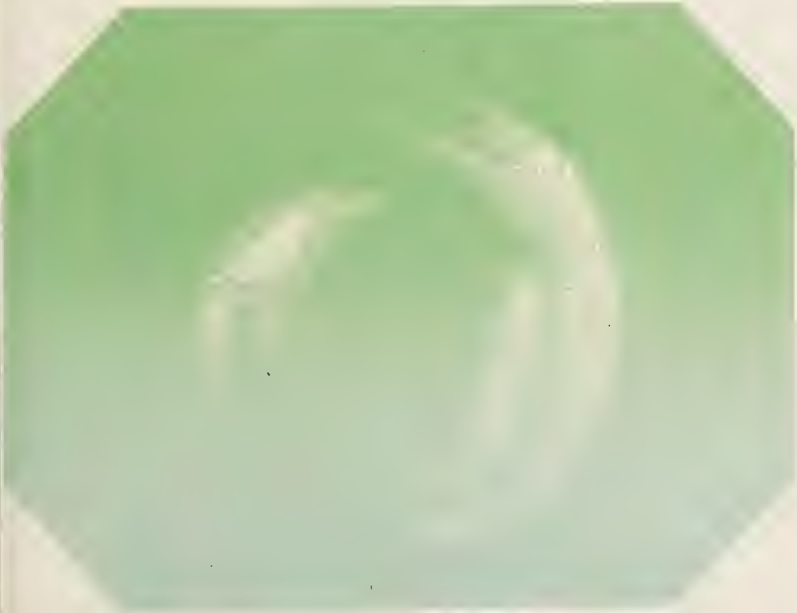


As in the Herschel Telescope



As in E. of Rosse's 3 ft. Reflector

In Small Telescopes



As in E. of Rosse's 6 ft. Reflector

Of the spiral nebulæ it is not possible to give so easy or probable a solution, though even there it may be that higher optical powers may result in still further resolution, or even separation and restoration to more symmetrical forms in accordance with known laws of gravitation. But it is just possible, even in the case of these nebulæ, that their revolution round the more condensed portion or nucleus of the arrangement may take place at a rate in which one portion of the system might maintain its general relation and apparent juxta-position to the other; though all positive assertion on the subject is of course unjustifiable in the present condition of our knowledge. Science will wait with deep interest to see whether further resolution or change of form can be effected in a spiral nebula. The nebula 51 M Canum Venaticorum is a fine example of the change already effected on a nebulosity, belonging at one time to both the first and second class, being both an annular nebula and a planetary nebula in Sir John Herschel's telescope; or, rather, an annular nebula, with a planetary nebula in its centre, and another planetary nebula external to it, the separate portions of which Earl Rosse found to be combined by further resolving power, and converted into a compound or double spiral nebula of the fourth class. Whatever the form or order of motion in this class of nebulæ may be, it is at all events remarkable that they appear to conform to the flat plane in their arrangement, and do not any more than the annular or planetary nebulæ assume the solid or spherical arrangement, which would be so embarrassing to explain on the principle of harmonious, common, or concentric motion.

Of the third class, or nebulous stars, it is still impossible to say whether the central, or interior, or otherwise optically associated stars are at the same distance or in the same plane with the apparently accompanying nebula, or whether they may not be merely intervening stars much more near, and projected factitiously on, or in association with, a nebulous background. That portion of the arrangement which is really nebulous appears to conform generally to the regularity of aspect found to prevail among the annular and planetary nebulæ; though it is just possible that one great central star in some of these remote regions may have, surrounding and in physical association with it, a dense revolving belt of luminous planets, comets, etc., conforming their orbits to its central attraction; just as it is possible to conceive that the great zone of the Galaxy might have a vast physical body or orb in its centre, instead of its united forces or attractions meeting alone in a common central point of mere vacant space, and thereby balancing the system. Such a central orb, added to a system mutually balancing itself independent of it, would of course add very considerably to the power of the central attraction; but as the tangential force is in every orbitual motion found to be the counterpoise or balancing influence against excessive central tendency, doubtless additional tangential impulse would prevail where additional central attraction was introduced; for the orbit, as Newton has established, is the balancing line of the two forces. What is above all things remarkable in these symmetrical nebulæ is their entire separation, both by distance and direction, from the Milky Way, and the regularity of form, in comparison with other nebulæ which we shall immediately have to refer to, to which their separation and direction appear to reduce them. Form thus seems to be the manifestation of order and harmony throughout the great universe of which we are a portion. It prevails from the loneliest desert flower, born to blush unseen, to the remotest star system or nebula, that gems the far silvery night of astronomical infinitude, and everywhere it is the symbol of presiding wisdom and fore-ordering fitness —of beauty, of perfection!

CHAPTER VIII.

Compound Nebulæ—Their probable Elements—Telescopic Illusions—Resolution of some Compound Nebulæ—Colour in the Nebulæ—The Great Nebulæ—Celestial Region of the Great Nebulæ—Probable cause of their greater distance and distinctive aspect—Nebulous Regions—Order—Gravitation—Importance of Physical Analogy—Remarkable aspects of the Great Nebulæ.

In the end of last chapter we referred to the nebula 51 M Canum Venaticorum, and it fitly introduces the first subject of the present. It is, as we there indicated, at once a spiral and a double or compound nebula, as now resolved and developed by the higher telescopic powers. Are there, then, compound or multiple nebulæ of other forms, and may we expect in this region to find still further variety and nebulous extension? The experience of astronomy has already answered this question in the affirmative. The nebula in Canes Venatici is not even the only compound nebula of its own class, for 4892 H Pegasi is also a spiral and a compound nebula. A spiral elliptically shaped, apparently from foreshortening and the irregularity of its position, crossed at one edge by a broad tangential bar, or mass of nebulous matter, which appears united to the edge of the spiral, though possibly it may be found by higher resolution to be a distinct and widely separated nebula of the spiral disc or annular character, placed edgeways to us.

Another compound nebula, of probably the same class, though Sir John Herschel has not been able to resolve it so far, is situated in Virgo, and its appearance, as given in his representation of it, looks very like a dim or hazy reduction of that in Canes Venatici. The Dumb Bell nebula may also be looked upon as a compound nebula, and a very remarkable multiple one occurs in the great nubecula, or Magellanic Cloud. Lord Rosse has also given a drawing of a beautiful one, consisting of two spiked club heads placed together, partially surrounded by luminous streaks, curved like arcs of an ellipse, which, if completed, would embrace the two spiked central masses in an egg-shaped enclosure. It is quite evident that even Earl Rosse's great telescope is not powerful enough to develope the true shape of this distant nebula, and that its present appearance is in all probability quite as delusive as that of 51 M Venaticorum, before mentioned, when it was observed by Sir John Herschel's instruments only, and before the application of Lord Rosse's greater power had discovered it to be spiral.

The result, then, of our consideration of these irregular multiple and peculiarly shaped nebulæ is rather a series of questions than any satisfactory or definite conclusion. How far are they yet resolved? What changes may still take place in their appearance by further resolution? How far is their complex and irregular appearance due to the occurrence and optical combination of distinct and widely separate annular and disc or planetary nebulæ, situated one behind and far beyond another in the receding perspective of space, and incidentally united and strung together by the line of our vision or point of view? Is it not possible to conceive that in looking through the central aperture of an annular nebula, of which 4892 H Pegasi may be a fine example, we may see thirteen or fourteen other annular nebulæ of nearly the same dimensions, diminished by distance, yet nearly concentric with each other, and at last apparently centred by a planetary nebula, far more distant than them all? That such a combination would be a most extraordinary coincidence is true.

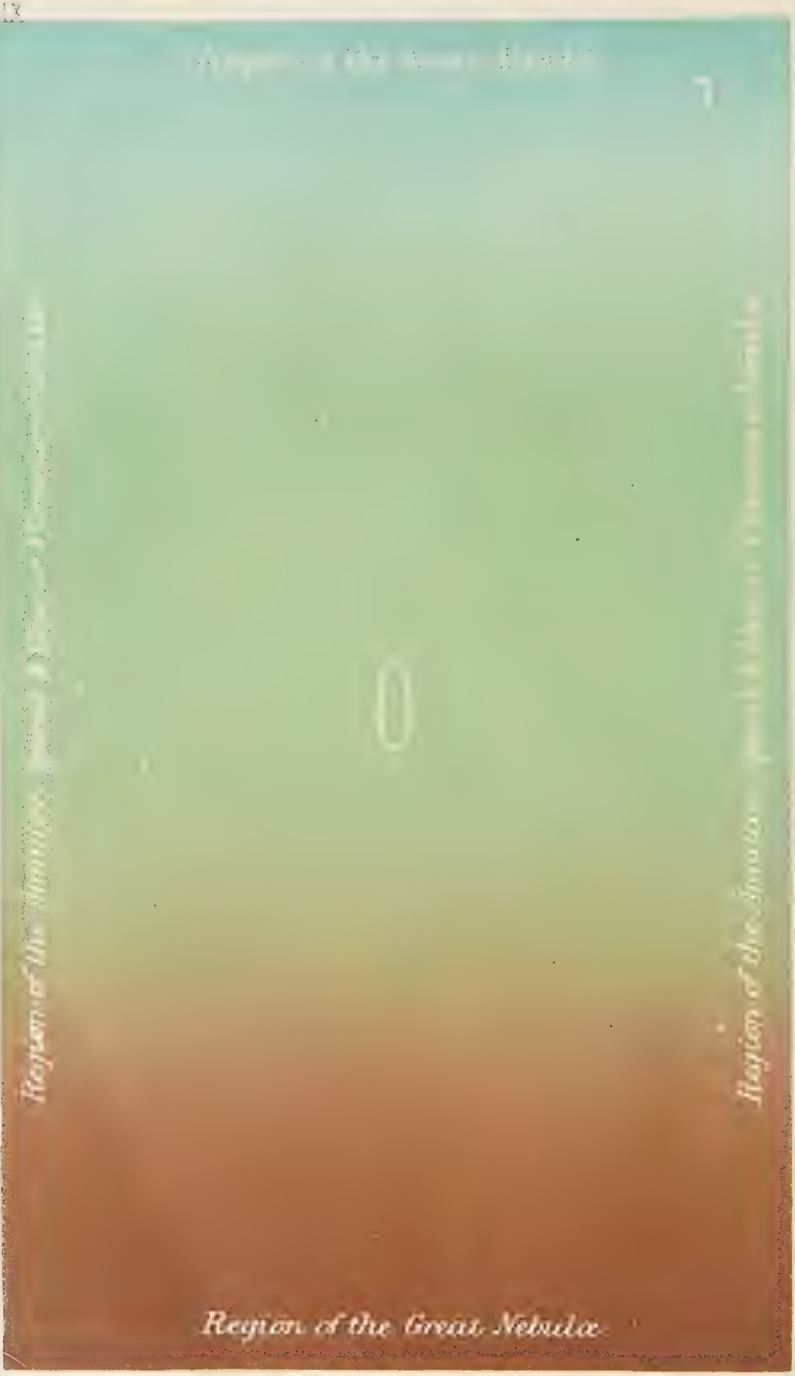
But where space is penetrated so far as the great telescopes now plumb and sound its depths, many singular optical coincidences do occur, and many more may be expected. Not that there is any wish to insist on this suggestion; it would be impossible, in the existing state of our knowledge, to do that. But when we find such a development and change in the appearance of a nebula as that in Canes Venatici, already referred to, taking place as the result of mere increased resolving power, and when we find the Dumb Bell nebula—so justly named according to its appearance in a small telescope—developed into an egg-like luminosity, with something like a lady's waist in its centre when looked at along the shorter axis of the elliptical enclosure, as delineated by Sir John Herschel, and finally fractured and separated by Earl Rosse's six-feet reflector, into two wholly distinct and separate masses of star clusters, shapeless and utterly unconnected with each other, even by a streak of intervening luminosity, we must not be unprepared to find ourselves, with all our existing and truly magnificent optical triumphs, still victims of the most grotesque and absurd optical illusions, and only a little less superstitious in our star-gazing than the ghost-seers of mediæval darkness. Analogy and experience point strongly to the conclusion that every compound or multiple nebula is resolvable and separable into distinct and unconnected components; and though it is true that in the case of 51 M Canum Venaticorum further resolving power has combined rather than separated the nebulosities, and united all their previously distinct components, it is also true that in the Dumb Bell further resolving power added an elliptical luminous envelopment to the nebula, which had no real existence whatever, save as an optical illusion at that stage of increased development, and also strengthened the waist-like connection between the two masses to which we have already alluded, and which connection was wholly unreal, and totally disappeared before

Lord Rosse's great reflector. It is a singular but most important part of the great question of LIGHT, why and how these illusions exist, and are so permanent and positive at certain stages of our optical power, as to be renewed and maintained whenever that power is reapplied, and we may possibly take occasion to recur to the subject again.

The expectation of science is that many nebulæ will yet be resolved into distinct stars, consisting of star clusters and star groupings and arrangements, such as some of the nebulæ have already demonstrated; and it is strongly suspected now by the most eminent astronomers that all nebulæ are resolvable into the same or similar results, though human powers of observation will never, in any conceivable likelihood, be great enough to achieve their total resolution. The space-piercing power of the telescope has already passed clear through so many of these groupings and star clusters that a strong basis of induction has been accumulated and established in support of such a conclusion. Many clusters and planetary as well as annular nebulæ have been already so resolved—of which the nebulæ 47 Toucani, 57 M Lyræ, 2 M Aquarii, etc., are well-established examples; and very many others of all forms and varieties of distribution might be added to the list.

Many of the planetary nebulæ, it should also be mentioned, have the peculiarity of colour—blue being, however, the only tint they have yet been found to manifest. This in several instances is peculiarly beautiful, the tint being light indigo, cobalt blue, or sapphire. They also flash this light in a peculiar manner, which renders them objects of great interest and attraction. One in the Northern Cross, No. 3,365 of Sir John Herschel, has the brightness of a star of the sixth and seventh magnitudes, with a pale indigo light; 4,964 H Andromedæ is 12″ in diameter, very bright, with a flashing cobalt-blue colour; 4,234 H Herculis is a bright 8″ diame-

Plate IX



[illegible] the Galaxy with reference to surrounding Uranography

[illegible] Great Nebulæ surround the Galaxy on all sides in the plane of its ter planetary nebula, cobalt blue; 4,373 Draco is also a cobalt-blue, light-flashing planetary nebula; while 4,628 H Aquarius is similar to the last; and 2,102 H Hydræ is also blue, very bright, and 32″ in diameter. In 47 Toucani, above mentioned, which may almost be called a planetary nebula, or a planetary centre with a surrounding ring, and which is a magnificent object, the central stars are of a fine pale rose tint, while the external ones are of white light.

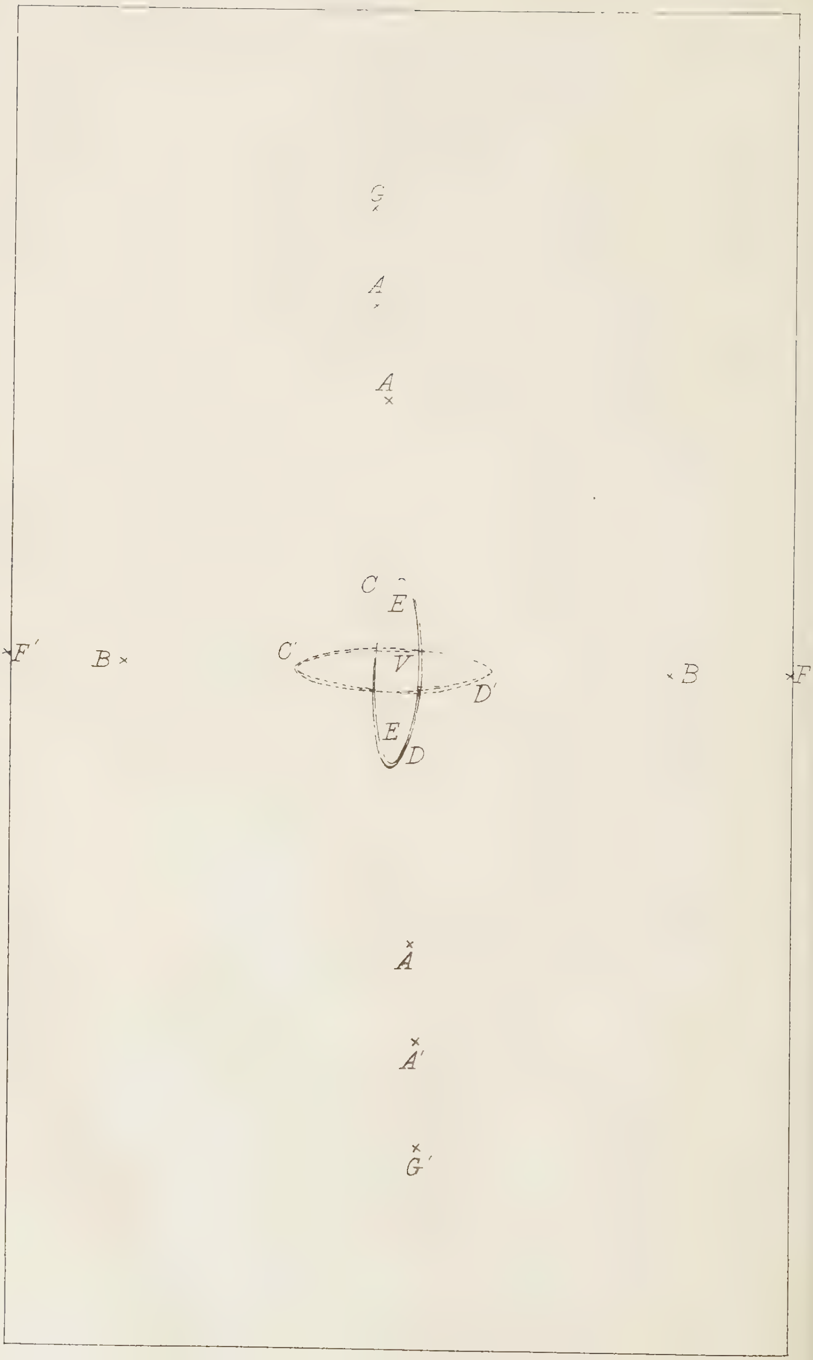
We now come to the consideration of a totally different class of nebulæ, the fifth class, or irregularly shaped nebulæ, mentioned in the classification of last chapter; a class so distinct in many characteristics from all those we have yet been dealing with, that they could not well have been treated along with the others without doing them the greatest injustice, and creating some little degree of confusion in a subject on which every element of discrimination is so desirable for our instruction.

The irregular nebulæ belong to a different region of the heavens, as well as to a different class from the others; for while those we have just been considering occupy regions almost as widely as possible divergent from the zone of the Milky Way, irregular nebulæ appear to shun these regions altogether, and to cling more nearly to the great plane of the Galaxy. They are generally larger also in their dimensions, occupying a wider field of view, and may, therefore, as a prevailing feature, be called, as they generally are, Great Nebulæ. Of these, the great nebula in Andromeda, the great nebula in Orion, and the great nebula surrounding η Argus, are fine examples, as well as the great nebula—30 Doradus. These nebulæ are not like any of those we have already described, capable of being reduced to definite form, or resolved, like the crab nebula in Taurus and others, into closely crowded star clusters. They resist the highest resolving power of existing optics, and stand shadowy and vague and dim, like phantoms bestriding the illimitable distance, and opposing the further penetration of space.

Are these irregular nebulæ then really more near, or are they not rather much more distant, and therefore more intangible than the others; being perhaps nebulous regions with their mighty components shadowily revealed, and yet half hid in the oblivious mantle of their own incalculably remote obscurity? By what means or elements are we to answer such a question? Or are there really none such? and must silence as well as oblivion be accepted? It will be hard to make human nature accept or acquiesce in such a blank conclusion; for again and again will persevering science turn her telescope to these regions of perplexity; again and again will reason and speculation and analogy recur to and revive the subject, and re-discuss and ventilate it in every way, in the hope of rending the veil of dubiety at some point, and catching a stolen glimpse behind the scenes, and penetrating, in some degree at least, this great mystery of the material universe.

It does appear, however, that this subject is not quite beyond our grasp. It is true that we can neither measure the distance of the one set of nebulæ nor of the other. Our largest base has been tested on nearer and intervening objects, and has failed to grasp their position in its minutest appreciable angle. Yet our standard for reaching even this far outlying fact is not absolutely without all foundation in known and accepted truth. Our impression is that these "great" and irregular nebulæ are more distant than the regular nebulæ, and are indefinite nebulous regions, optically united in their components to some extent, rather than single nebulæ in themselves; and our reason for this conclusion is founded on the position and plane of the Milky Way, and may be explained as follows, with reference to the accompanying plate.

There are two directions in which the attraction of such a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A′
G′

body as the Milky Way would take effect. Assuming it, as we have already done, to be to distant observation, on we believe the unquestionable tendency of all scientific indications or analogies—either an annular or a planetary and disc-shaped nebula, possessing a central plane with which the distribution of its sideral elements coincides,—the one direction would be in the extension of its plane, and the other in the extension of its axis. These two directions would form the maximum lines of the Galaxy's attractive forces, and it will be manifest to a little consideration that the two axial attractions come to a period which must be much nearer to the centre of the annulus than a circle of attraction equally powerful and remote in the direction of the extended plane. Thus we cannot believe that two bodies situated at equal distances, A and B from the centre of the annulus, can have the same amount of attraction to contend against in maintaining the insulation and independence of their position, either as totally independent nebulæ, or totally independent star clusters or star systems. To the independent body situated at A the attraction, and the consequent perturbation and liability to derangement and even absorption by a superior force, or by the blending and confusion of mutual and nearly equal forces, must be much greater than to the same body if situated at B. In fact, it would obviously require two annuli or rings, transverse to each other, like the galactic ring C D and the dotted ring C′ D′, to equalize the attractive force, and make the attraction exerted on B equal to the attraction exerted on A. It must hence follow that a body at B, where there is but the one annulus, such as the Galaxy, situated transversely to it, as C D, does not require to be so distant from the centre of the annulus as a body situated at A would require to be before being subject to only the same amount of gravitation or attraction from the annulus. We are not aware that the problem has been mathematically dealt with before, and therefore it is one of some delicacy as well as interest; but just as certainly as bodies situated at C′ and D′, when there is no transverse ring, cannot be under the same degree of attraction as bodies situated on the ring at C D, so neither can they be subject to the same attraction at B as at A. The maximum of all the attractive forces of the ring C D must be in its centre at V, and from thence it must diminish along the axial line C′ D′, according to the squares of the distance; but it will not decrease in the same ratio in the direction from V to C or D along the radii of the plane of the ring itself, for the ring is the source of the attraction centred at V; and all bodies within the ring, as they recede from the centre and approach one side of it, just draw nearer to one part of the source of attraction in proportion as they recede from other parts of it. The inference from which would be, that if the ring were perfectly equal in all its parts, the attraction within the ring would be equal at any point of the entire area or interior plane to the attraction at the centre point V, so that the attraction would not begin to diminish in the direction of the plane of the ring until a body was external to the rim of it. The result of this would be that the body at A would require in that direction to be as distant from the rim of the ring as B is from the centre before it was as free from the attraction of the annulus.

Let us now suppose the earth situated in the ring and forming a part of it at E or E′. It must follow that here it is much nearer to a nebula at B than to a nebula only equally freed from the attraction of the Galaxy by being situated at A′. If the Galactic ring be 1,279,733,800,000,000,000 miles in diameter, as estimated in a preceding chapter, and the object at B be as far distant from the centre of the ring as twice its radius, it must follow that B must be distant from V a point intermediate between and common to the earth's positions at E or E′ no less than 1,279,733,800,000,000,000 miles, while A′ must be from the same point at the greater distance of 639,866,900,000,000,000 miles *more*, so that A′ would require to be about one-third further distant from us than B to be equally free from the area of attraction of the Galaxy. Now, the distance of the heavenly bodies is so completely subject to a distribution of space among them on the principle of securing entire freedom from confusion and collision in their motions, and so completely is this principle prevalent in every instance with which we are acquainted in every region the telescope is privileged to explore, that we cannot reasonably doubt the fact that the nebulæ must be subject to the same laws of distribution as single bodies or multiple systems are made to yield to.

Taking our point of observation from the earth at E, and the distance of the nebulæ we have hitherto been dealing with at F F′, the distance of the irregular or "Great Nebulæ" we are now about to consider would be the semi-diameter of the Galactic ring further distant, at G G′. It must be obvious that at such immensities of distance as we have been considering a difference like this must have a very serious effect on the aspect of a body of equal character and dimensions situated first at the one distance, and removed afterwards to the other; and that the difference in the aspect of the body under the effect of this distance would be much greater than the difference of appearance it would present when viewed by Sir William Herschel's great telescope, as compared with its appearance in the great six-feet reflector of Earl Rosse; and what that difference is we have already seen in the case of the Dumb Bell nebula and that of 51 M Canum Venaticorum, marked 1622 in Sir John Herschel's old catalogue, and 3572 in his new catalogue of 1864. In fact, the very circumstance of the greatly increased spaces occupied by these great nebulæ at such an increased distance is enough alone to demonstrate that they occupy the spacial area not of mere single nebulæ, such as we have already made acquaintance with, but of nebulous regions vast enough to contain hundreds of nebulæ of the first four classes. What, then, is the inference pointed to by such considerations, but that these great, dim, and hazy nebulæ, whose very irregularity, immensity, and vagueness are their distinctive characteristics—whose untraceable and shadowy spread of vapour-like, melting, and half-hid outlines forms the most prominent feature of perplexity with regard to them—are in reality hundreds of nebulæ apparently united and blended together with phantom and deceptive luminosity, like the fictitious elliptical halo and junction with which Sir William Herschel's telescope invests and unites the Dumb Bell? How can any such luminosity yield a spectrum analysis? We should as soon think of testing the spectrum analysis of a ghost, or a night-mare, or a dream. To come to the conclusion that because such a spectrum presents no elementary lines it must be the spectrum of a vapour, would be vapouring indeed, and with very thin vapour. All honour to spectrum analysis! but we trust we are too jealous of the integrity of scientific truth to accept implicitly the first suggestions and unfledged conclusions drawn from it—too appreciative of its great achievements, too respectful to its already well-won and wonderful laurels to drag it through the mire in support of hasty and ill-digested inferences.

Looking, then, at the whole circumstances, and at every element of fact or analogy, we have to aid us in this investigation as yet, we cannot help the suspicion that the great nebulæ in Andromeda, Orion, Argo, and Dorado are nebulous regions very greatly falsified and over-represented in their appearance by spectral and fictitious light, and that no single nebula or grouping or combination of stars fills the entire field apparently occupied by any one of them. But in each of these regions, and contributing their share to the optical illusion under which they are at present exhibited, countless nebulæ and star clusters, of distribution and forms with which the reader has already been made familiar, are congregated in the immense perspective, blending optically, or dispersedly distributed in ways and arrangements perfectly regular and harmonious in themselves, but rendered grotesque to us merely by the factitious circumstances of our point of view. Too much importance, therefore, must not be attached to the adventitious position we occupy with reference to bodies so distant, so immense, and so highly complex in the arrangement and dependence of their myriad elements. Confusion is nowhere in nature; creation's master-law is order. The sands on the sea-beach may appear to lie in heaped perplexity and derangement; but the great law of gravitation has its grasp on every atom—every trivial crystalline fragment of the innumerable mass. The wind may blow it—the wave may roll and wear and spread its tiny form far away over its associated sand-grains, attriting and being attrited by the sharp angular facets of itself and its companion atoms; but between each such impulse applied to it and the great law of gravitation there is exercised a precise balance of concurring and co-operating, not conflicting, forces which renders each new and transient resting-place it finds as certain, as inevitable, as if it were endowed with perfect intelligence, and exercised from choice the powers by which it is wind-borne, wave-tossed, and, to appearance, merely drift-scattered and carried away. And here, in these mightier regions of space, whose distance is dusted with stars, and planets, and satellites, and nebulæ, and systems which the immense perspective has optically crowded together till they lie as thick to human vision as the sand-strewn, wave-dashed, and wind-drifted shore, the same great law of gravitation maintains its far-reaching and universal grasp—a mighty power, a strong upholder, an absolute and supreme distributor and disposer—holding the created universe in its gripe like the fettered and down-riveted prisoner of an iron and a master will—unseen, inscrutable, but irresistible—and as potent as if it verily veiled within it the omnipotent right hand of God!

What if increased optical power should yet enable us to penetrate this veil of distance, behind which mystery maintains her obdurate incognito for the present, and reveal to us star clusters, nebulæ, systems, and arrangements of which we have types and instances already within our astronomical view,—would it be strange to find it so? Would it not be stranger, rather, that with all the space which science has now made subject to her domain, no instance whatever existed illustrative of the manner in which space is occupied around and beyond it? Do we justifiably dare to suppose that because we have reached the limit of a certain achieved optical power, we have therefore and concurrently achieved the universal boundary of a particular order of things, beyond which all is different and all is new, and absolutely unparalleled in existing experience and knowledge? Were such the case, would not the coincidence be a solecism in scientific experience—a baseless exception to every analogy? Would it not be almost a violation of the connective and harmonious persistency and universal co-operation of truth? Every consideration entitled to command our attention and respect conspires to make us pause before ascribing to the Great Nebulæ, as an absolute and permanent characteristic, their present irregular and capricious appearance. We are but groping at them yet in the darkness and impenetrability of their distance, from whence, like phantom objects in the vagueness of night, they present themselves to the imagination rather than the sense, and in forms unreal as ghosts and apparitions conjured by superstition from the factitious light and shadow thrown by gloom and terror over dimly seen realities, whose true outlines are falsified, disturbed, and played with by the faint flicker of imperfect light, strug-

NEBULÆ

Great Nebula in Andromeda

gling with the mighty 'blanket of the dark.' Whatever further and future telescopic power may reveal, therefore, we do expect that it will, when it furnishes us with accurate and reliable knowledge, show forms and arrangements in strict harmony with the great and as yet all-prevailing law of gravitation, whose range we are led to recognize as co-extensive with that of matter as it now is, if not as universal as truth and infinitude. Not that we would by any means maintain that gravitation is self-existent. It is, after all, but the law, not the lawgiver. And what law may not be cancelled by the enactor? Neither would we have it understood that we expect no new phenomena when the range of our present optical vision is expanded by additional telescopic power. Variety, so inexhaustible within the limits of minute creation everywhere, cannot be less powerful or native to the same great Hand in the boundless regions of immensity. What we wish distinctively to say is, merely that the same great laws and characteristics of order and fitness and mutual relation, which are found to prevail through all the interminable variety of terrestrial creation will not be less apparent throughout those mightier regions which are subject to the same great sway, when, if ever, we are rightly enabled to comprehend them.

In the meantime these great nebulæ are certainly most wonderful and startling phenomena, and their present accidental resemblance to shapes and forms suggestive of faces and figures is a singular and fascinating feature of them, which may well make them objects of the deepest interest and curiosity.

The great nebula of Orion, when fully detailed under a certain telescopic power, it will be seen, has an appearance like that of a human figure with head and lower limbs torn off, and gashes in the neck and breast. The portion of it surrounding the celebrated trapezium we have so often mentioned already (θ Orionis) has an appearance somewhat resembling that of the face of a blind and age-stricken lion gashed and torn in some fierce war with his kind, or smitten and distorted by cancerous disease.

The great nebula in Andromeda is like nothing so much as a dead bird dropping powerlessly, head downward, from its airy flight, like the victim of some fatal marksman.

The great nebula 30 Daradus has just enough of the features of a face to perplex and at the same time stir the fancy, and so much more than enough for one face as to make it somewhat suggestive of a heap of skulls of different kinds confusedly overlying each other.

The nebula round Eta Argus is as yet too vague to be positively suggestive of anything definite, and one is apt to suspect that its distance is greater, or has not yet been so successfully dealt with as the others. Indeed, Sir John Herschel's language, descriptive of it, would almost imply as much, without in all probability being intended to convey precisely that impression. He says: "With an 18-inch reflector, no part of this object shows any sign of resolution into stars, nor in the brightest and most condensed portion, adjacent to the singular oval vacancy in the middle of the figure, is there any of that curdled appearance, or that tendency to break up into bright knots with intervening darker portions, which characterises the nebula of Orion, and indicates its resolvability."

(By G P Bond)

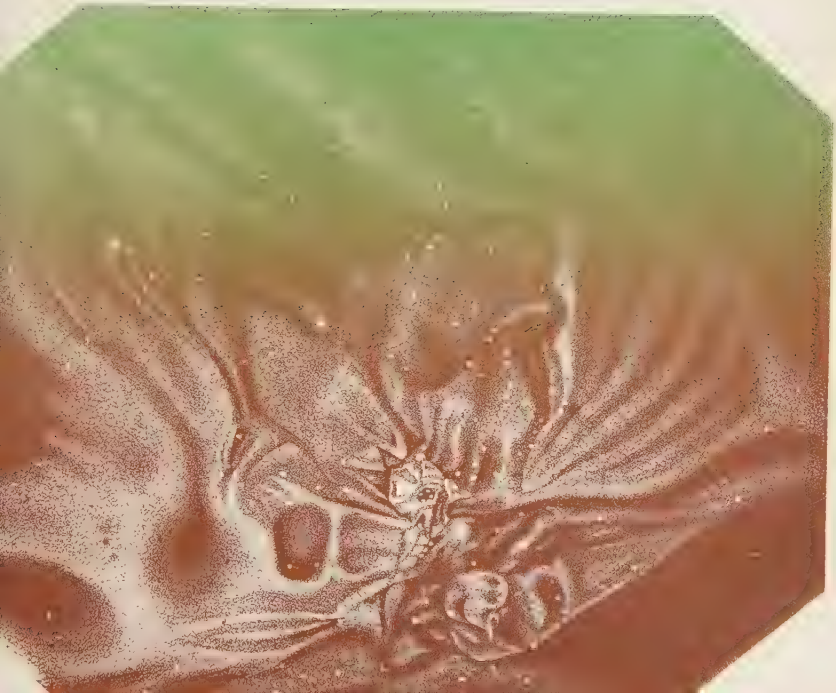
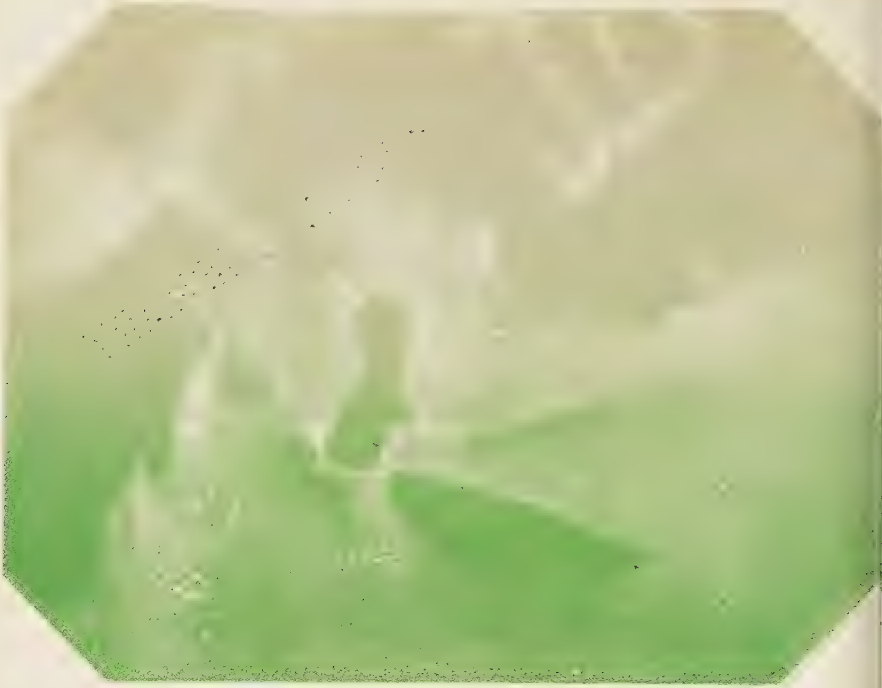
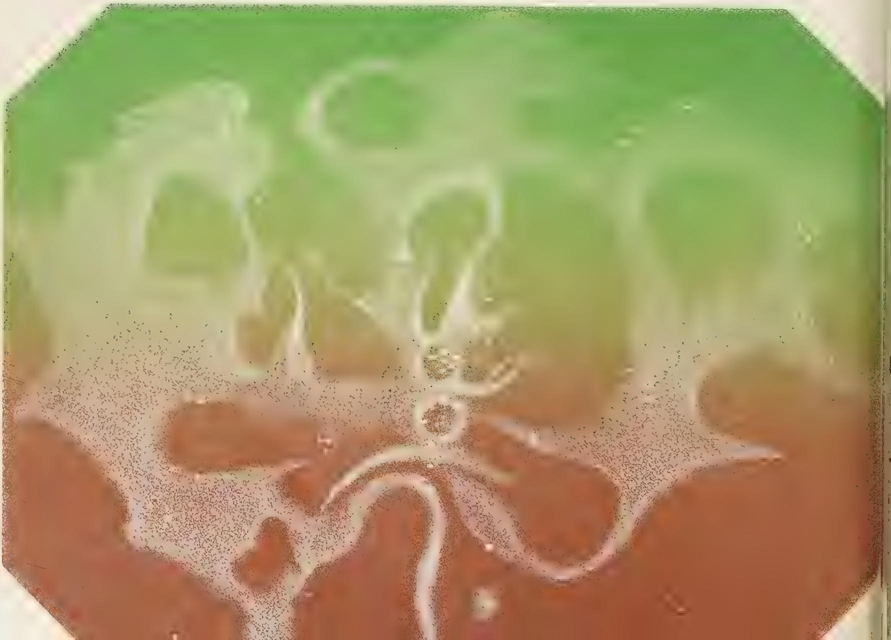


Plate XIII.

GREAT NEBULÆ.



Great Nebula surrounding Eta Argûs
(By Sir John Herschel)



CHAPTER IX.

Variability of the Nebulæ—Irregular Star Clusters—Analogies of the Irregular Star Clusters—Star Groupings and Sideral Arrangements of Space—Spectrum Analysis—Some possible Limits of its Action—Sideral Elements already discovered by Spectrum Analysis—Importance of it in Observations of Coloured Stars—Spectra of Comets—Indications of unknown Elements in Star Spectra—Facts in Support of Spectrum Analysis—Attraction, Gravitation, and Chemical Affinity, their probable identity.

Some characteristics of the nebulæ still require to be dealt with, and among these one of the most striking is their variability. M. d'Arrest, of Copenhagen, appears to have drawn recent attention to this subject first from an observation he made on 3rd October, 1861, of the small 1′-diameter nebula discovered by Mr. Hind in the constellation Taurus, in 1852, in connection with which he discovered subsequently a variable star of the tenth magnitude, since reduced to the twelfth. M. d'Arrest, on the date mentioned, found that this nebula had totally disappeared, and, though his report was doubted at the time, it has since been fully confirmed by the observations of Le Verrier and Chacornac at Paris, and Secchi at Rome. This nebula has subsequently reappeared and disappeared again. Mr. Pogson and others have also observed similar changes in the cluster 80 of Messier's catalogue of Nebulæ near to R and S Scorpii. A variable nebula has also been discovered in Draco; another in Taurus, near Merope, one of the stars of the Pleiades; and another was discovered, also in Taurus, by Chacornac, in October, 1855. These, however, are all nebulæ of small dimensions, and Sir William Herschel had long since excited curiosity on the subject by his observation of two nebulous stars which, though seen surrounded with nebulous circles in 1774, were found, on subsequent examinations many years afterwards, to have no nebulous appearance. Other instances have been observed among the small nebulæ since then, and previous to M. d'Arrest's later revival of this subject; but in the great nebula in Argo, mentioned at the conclusion of last chapter, a variability has also been observed which seems to be intimately connected with the variable star Argo, of which mention was specially made in a former chapter, and which sometimes changes from the appearance of a star of the first magnitude, rivalling Sirius in brightness, to a star of the sixth magnitude. In 1838, Sir John Herschel found this star, then of the first magnitude, situated in the densest portion of the great surrounding nebula. In 1863, it was found by Abbott, at Hobart-town, to be of the sixth magnitude, and entirely free from nebulosity—a fact confirmed by Powell of Madras, who states that he has observed other changes of the nebula affecting its brilliancy and shape. Father Secchi, O. Struve, and others, have also found that a change has taken place in the great nebula of Orion. This was perhaps to be expected, if our suspicion of the components of these great nebulæ has any foundation.

Another feature of the nebulæ to which attention may be drawn in connection with their distribution already noticed is, that only at certain points has the Milky Way a nebulous irresolvable background, but annular nebulæ of similar character, though immensely more distant from us than the Milky Way—such, for example, as 57 M Lyræ, before noticed—have been completely resolved into extremely minute stars by the telescopes of Earl Rosse. Is it likely, then, that the Milky Way is so irresolvable as has been assumed? or is it not much more probable that the irresolvable nebulous background found in some portions of the zone consists really of distant nebulæ of the character of the Great Nebulæ wholly unconnected with the Milky Way, and merely seen through it? And are we not somewhat misled as to the character and density of the Milky Way—yet without at all requiring to qualify our minimum estimate of it, or the majestic dimensions we have before assigned it—by facts or possibilities like these which have not yet received due consideration? It must be remembered, from the extent to which resolution has already taken place in very remote star clusters, annuli, and planetary nebulæ, that an absolutely irresolvable nebula implies immense and immeasurable distance. There is, on the other hand, nothing that can be logically urged to exclude the idea that nebulæ lie far outward from us in the extended plane of the Milky Way, just as well as in all other directions. We should be much more surprised with the daring than the science of any astronomer who asserted that there were not or could not be any nebulæ in this direction which, from their position, could only be seen through that intervening stratum of stars which we find uniformly interposed between us and the nebulous background of the Galaxy; as well as at other parts of its zone through which no irresolvable nebulosity has been discovered. The subject is important enough to justify attention at least, and we assert nothing more than the necessity for that.

Let us now direct attention briefly to some of the resolvable star clusters, many of which have altogether irregular appearances, conforming to no symmetrical principle of distribution, but thrown together, so to speak, at seeming random, as if in violation of the law of order. Of these the Dumb Bell, already mentioned; 11 M ANTINOI, 30 M Capricorni, 5 M Lyræ, 52 M Cephei, and many others which might be named, form excellent examples. And the eye accustomed to look at the annular and planetary nebulæ before described is apt to feel that something is altogether wrong in these apparently exceptional and capricious instances. To take up and entertain such an idea seriously, however, would be a very great mistake. Just let any one imagine himself for a moment placed as a distant observer of the solar system at some point perpendicular to the great plane of the ecliptic in which most of the planets move round the sun. Would such a view of the solar system present anything like symmetrical arrangement to the eye of the observer? Would he not instead find the various planets and planetoids at all sorts of angles and irregular positions with reference to each other? Some in or near conjunction, or on the same side of their orbits; others in or near to opposition; and some at other points of their orbits, just as might happen at the particular period of observation. Their orbits and the fine and balanced regularity of the whole which orbitual motion involves would not be discoverable by a mere glance at their relative positions, but would be the result only of careful watch and vigil; and even when discovered, the fact would not give their distribution an *appearance* of symmetry. At no part of their orbit have they that appearance, even for a moment, at any time. Neptune, for example, would be found only at one portion of his orbit at any one period, without any other balancing or symmetrically placed or apparently co-operating body at any other point of it to give the aspect of counterpoise and order. So of the earth, and so of all the other planets. With these resolvable star clusters, then, the same characteristic may prevail, and, amid the apparent disorder, the real harmonies of beautiful and exact orbitual motion and mutual gravitation and attraction may reign without our being able to perceive or trace any of those invisible phantom rings or ellipses in which the luminous orb, only seen at a point, describes its motion so persistently and accurately round its centre of attraction. Even that singular cluster called "the Crab Nebula in Taurus" may have all its elements conforming to this rule, though it is quite possible that a "half-face" view of such an annular nebula as 57 M Lyræ or 97 M Ursæ Majoris might give all the peculiarities of appearance represented by the singular and seemingly capricious distribution of the elements of "the Crab."

From the constitution of the star systems, star clusters, planetary and annular nebulæ, and nebulous stars which have been distinctly seen and resolved, we may be able to gain a general idea of the constitution and character of matter distributed through space; and we may safely say that the region accurately known is now so comprehensive, and so free from exception, as to form a very important exemplification of the systems outlying and beyond it in the oblivion and invisibility of still all-surrounding and impenetrable infinitude. We may fairly conclude that the irresolvable nebulæ and the vague and exceptional nebulous forms and shifting and shadowy outlines which we fail to determine by our optical powers are all more distant than the resolvable nebulæ and clusters, and therefore do not form exceptions within the same range of space. We have thus certain knowledge that the area of clearly ascertained space consists of annular and planetary or disc-shaped arrangements of stars, irregular star clusters, subordinate star systems, and, inferior to these, single-sun systems like our own, with independent planets, planetoids, satellites, and cometary bodies, and that these comprehend the whole known varieties of stellar groupings and arrangements. The star systems we have already indicated are in all probability connected with the great annular system of the Galaxy. The annular nebulæ seem repetitions of the Galaxy at independent distances. The planetary nebulæ seem to be stellar arrangements on the same principle, with merely the interior vacuity of the annulus filled in; and the irregular star clusters are probably extended and independent star systems having mutual dependences and motions—a solar system on a great scale, with, it may be, much larger as well as more numerous self-luminous planets and satellites, and possibly possessing dark subordinates which we may never be privileged to perceive. Far stretching beyond all these, we catch dim and spectral glimpses of distributed matter, changeful and dreamy in character, like the vague and incoherent current of thought running through a half-slumbering mind—just enough to tell us we have not yet reached any boundary of the infinite—that onward and onward for ever we should still find order, and light, and motion, and stellar arrangements; and that it is to our fixity, to our feeble powers, to our evanescent vapour called life, that limit and definition and impassability apply.

Of the physical constitution of these various bodies it is not possible as yet to say much. The prevalence of the great law of gravitation over all, indicates at least that the various bodies have some degree of chemical affinity for each other; and that, if not composed entirely of the same elements, or proportions of elements, they are of matter closely allied. Spectrum analysis has already done something in this line of inquiry, but there are many difficulties in the way. The solar spectrum has already revealed the presence of barium, cadmium, calcium, chromium, copper, iron, magnesium, nickel, sodium, strontium, and zinc, according to Kirchhoff, with a suspicion of two other metals, cobalt and potassium; and more recently in the solar chromosphere, which is the region of the coloured or red luminosities above and external to the photosphere, hydrogen has been discovered. This fact rather confirms a remark we have already made in an early chapter of the present work, that the luminosity of the sun must be maintained from the absence of hydrogen, or the very small proportion of it which exists among the external gases of the solar envelope. That the hydrogen of the sun should be found in the upper region of its atmosphere is quite a proof that there is not enough of it to combine into dense vapour, or be precipitated on the surface of the sphere in the form of water. The presence of oxygen and nitrogen in the atmosphere of the sun, we see no reason to doubt, though the spectrum has hitherto failed to discover them. Perhaps there may be some difficulty in passing the spectrum of solar oxygen and nitrogen distinctively through the dense stratum of the terrestrial atmosphere, composed of precisely the same elements; but the position of hydrogen in the sun shows that there is only enough of it to be expanded by the solar combustion and heat into a light and high-floating gas pervading the upper stratum of the solar atmosphere, in quantity too limited to combine into water under such circumstances and claim a lower position among the heavier matter of the solar surface. Its elevated position, indeed, can hardly be explained on any other chemical theory.

As for the limited number of other chemical elements found in the spectrum of the sun and other stellar luminaries, the fact is not so very surprising, from a purely chemical point of view, as it may seem to the very naturally and pardonably enthusiastic experimenter in the department of science newly opened up by this analysis—the surprising discoveries of which may have led hastily to the conclusion, under first impressions of its freshness, that everything is capable of being discovered by it. But, as the law of the spectrum is that *metalic vapours absorb the same rays which the same metals emit*, it is somewhat hasty to assume, for the mere sake of self-satisfaction in connection with this law, and, as appears to be here done, as an absolute corollary of it—that all the metals of which a star or luminous sphere is composed have at all times an appreciable portion of them in the form of metallic vapour in the atmosphere of such bodies, and that therefore the spectrum can always reveal the whole elements of which any such star or luminary is composed. There is no ergo or intrinsic sequitur here. The one proposition is not at all an essential concomitant of the other. It is quite possible that all the elements of which the earth is composed may exist in the sun; but does it thence follow that portions of all these elements must at all times, or at any one time, be found in the form of an appreciable quantity of elementary vapour in the solar atmosphere? We confess to great chemical difficulty in arriving at such a conclusion. But, while deeply indebted to spectrum analysis for what it has done in this as well as in other directions, we must allow that in this particular department of astronomy we are not unprepared to be disappointed as to its exhaustiveness. It is well that in Pollux and Vega we have (already?) found magnesium, iron, and sodium; in Sirius, hydrogen in addition; situated, doubtless, in the chromosphere of that orb also—if we were at all capable of distinguishing its chromosphere from its photosphere, which, from its distance, even with the highest optical power this world's science will ever be able to develop, it is to be feared we must never hope to be—that in α Orionis we have bismuth and calcium, and in other stars antimony, mercury, tellurium, and other elements also. *Pro tanto*, thanks to spectrum analysis! but still we decline to believe on its authority that Vega and Pollux are composed of only three elements, or the sun only of fourteen, or, indeed, absolutely and only of any further or greater but limited number of elements, which additional observation in this direction may yet reveal. We do not expect the *whole* truth from such a quarter; but in the meantime we would suggest that more close and frequent observation of the solar spectrum should be practised by those engaged in this line of investigation; for it is quite possible that a metallic element may be sometimes sublimated by the solar combustion which is not always to be found in the atmosphere or mingling with the photosphere of this luminary in a state of gas.

We do, therefore, still expect from spectrum analysis a good deal more in this direction; and whenever, especially, change of colour is taking place in a star, such as is known to be the case in regard to η Argus and others, careful and continuous observations ought to be maintained; for it is all but certain that colour is not due to conditions of combustion only, but also to the chemical elements involved in the combustion for the time. On this account all the coloured stars ought to be objects of the greatest interest to those engaged in the investigations of spectrum analysis in connection with astronomy. We trust that no remark we have ventured to make will be misconceived as proceeding from any disposition to discredit their labours, we only wish to guard against that tendency to charlatanry so much the infirmity of our nature, which so often leads to the premature proclamation of optimity on the discovery of every really good thing.

It seems quite possible, then, that these great suns and sideral luminaries contain in the immense masses of their matter many elements more than the earth's chemistry has revealed, even if we could say that the whole elements of terrestrial chemistry have been discovered—nay, that they contain many elements not within the limits of terrestrial chemistry; and we should not be surprised were the solar and sideral spectra to make us yet acquainted with lines which will be a puzzle and a perplexity to us for ever. The spectra of comets have already somewhat bewildered us, and seem to confirm the previous remarks we made as to the improbability of their being composed of any kind of chemical matter with which we are yet acquainted. Hence, we have a corroboration of spectrum analysis so far from an entirely independent quarter. The spectrum observations of the comets have hitherto been discrepant and conflicting, and therefore cannot be relied on. But the question is, not so much whether more accurate and corroborative results will flow from further observation, as whether the discrepancies which have been already recorded will not be quotable against all future records on the subject, and whether additional observation will not rather increase the perplexity. It is highly necessary to be forearmed against such possibilities, that we may not be repelled from the subject by mere discordance, but may rightly begin to understand it and appreciate its significance. We should not be much surprised, for example, to find in some future observations of the solar spectrum that the evidence of barium, chromium, cadmium, and calcium was found wholly wanting. And why? Not because we believe previous observations have been wrong, and not because we believe that in this particular case there is any real discordance or discrepancy, but simply that for the time being there might be no vapours of these metals in the solar atmosphere. Such a discovery, if made, therefore ought not to be discouraging, but to be rightly interpreted and thankfully accepted for its real and very important worth. It would be a practical warning to us against believing that the spectrum of any particular time was an exhaustive spectrum, or rushing to the hasty and immature conclusion that blazing and brilliant stars, like Vega and Beta Geminorum, are composed of only three metallic elements! How their combustion is maintained in such a case, forms, to the chemist at least, a somewhat embarrassing question. Sirius is said to have hydrogen in addition to magnesium, sodium, and iron; but even this addition does not much help the combustion question to the chemical understanding; and we shall doubtless, if we accept existing spectra as ultimata on the subject, have to wonder for some time to come how Aldebaran has been able to get up and keep alive such a blaze with even all the elements of antimony, bismuth, calcium, hydrogen, iron, mercury, and tellurium in his spectrum. It is well that suspicion is already being excited from peculiarities in the sideral spectra; that new elements, with which we are totally unacquainted as yet within the limit of this world's chemistry, are giving indication of existence; and that many of the lines are incapable of being chemically read. The subject is of immense interest, and will doubtless lead to a more searching investigation of terrestrial chemistry also, and in all probability to results the far-reaching importance of which it is as yet impossible even faintly to anticipate. That oxygen and nitrogen are components of all the sideral atmospheres, as we have already indicated, though not traceable in their spectra, we cannot help believing, and yet the possibility of ever discovering their existence by means of spectrum analysis we can perfectly conceive, for reasons before partially stated, to be highly problematical. We cannot, however, the less believe, according to the present physical constitution of material bodies, that the atmosphere they constitute is essential to sustained chemical combustion, and that the circulation of sideral elements undergoing combustion so continuously must have some such medium for sublimation, distribution, and reintegration; and we venture to think it will be extremely difficult to satisfy chemical requirements, and the explanations due to that great and accurate science, on any other hypothesis—unless, indeed, the suggestion can be sustained, that some other and unknown gases, of equivalent chemical importance for such a purpose, really supply their place.

But on this subject it is not without importance to consider how far the perplexities experienced in sideral spectra may not be due to the very weak or small proportion of elementary vapours or gases which may for the time being exist in the sideral atmospheres, in combination with the difficulty of distinguishing it from the proportion of the same element which may be in the atmosphere of our own world, and through which the sideral light has to pass in reaching us.*

This question, then, is still invested with so many special difficulties, with which spectrum analysis has not had to contend in dealing with strictly terrestrial chemistry, that we are required by all the interests and importance of truth to be extremely careful at every point that too eagerly desiderated and inconsiderate conclusions do not lead us astray. It is a most singular fact, if oxygen and nitrogen be essential elements to the combustion of the sun and stars, as existing chemical science plainly asserts with all the weight which indisputable analogy can carry with it, that the spectrum has never revealed these elements in their atmospheres. The defect, if it really be a defect—and we apprehend it will be difficult to convince any enlightened chemist that it is not one—has a trumpet-tongue with reference to the exhaustive reliability of spectrum analysis as applied to solar and sideral astronomy, which no trivial or indirect argument or explanation can dissipate or put to silence.

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* It is certainly of great importance that, if the metallic vapours of our own atmosphere were a primary cause of the spectrum lines, the lines differ when different stars are looked at, which could scarcely be the case if the state of our atmospheric chemistry were *alone* involved. Something, therefore, is clearly due to sideral peculiarity—but how much? And how far may not the peculiar condition of sideral combustion qualify the nature of the star-light they give? We have yet to ascertain that *every* kind of terrestrial light or artificial combustion would enable us to read the spectrum of our own terrestrial elements with exactly the same results. But we may hereafter give some suggestions, which have occurred to us, for applying to the whole subject a more crucial and exhaustive test.

Still, whatever doubt may be found to hang over the conclusions of spectrum analysis as applied to astronomical chemistry—and we do not for a moment wish to give any such doubt undue or exaggerated importance—there can, we apprehend, be little question that the truth is in the direction in which spectrum analysis appears to point, and that sideral chemistry must have a considerable analogy to, and even identity with, those terrestrial elements of which the chemist has given us such good and reliable account. Indeed, it is difficult to conceive that attraction and gravitation are not, in a great degree, identical with chemical affinity, if not wholly manifestions of it.

CHAPTER X.

Gravitation—is it continuous as well as universal?—Unity and Personality of Omnipotent Power—Immateriality of Life and Power—Boundlessness of Space—Optical Boundary of Space—its possible appearance—Vastness of Sideral Chronology—Illimitable Powers of the Soul—Our Intuitions of Immortality.

We may now consider ourselves as having attained to a very considerable knowledge of how astronomical space is occupied, and the laws, the chemistry, the distribution, mutual dependence, and motions of material bodies distributed through it. But at this stage a strange question suggests itself. We have spoken on the authority of great philosophers, who have long done so before us, of the universal law of gravitation, and we have seen something like evidence of its influence over system after system and nebula after nebula of the mighty and far-spread sideral arrangements we have been privileged to survey. But is this universal gravitation continuous and unbroken, as well as universal? or must we consider it as an influence distributed, like matter, in insulated areas or spherical spaces, between which no gravitation exists, just as matter and material chemistry do not exist between sphere and sphere? We have found satellites dependent upon planets, and planets upon suns; suns in turn bound in binary and multiple systems to other suns, and these multiple systems again forming portions of great ring systems, or annular and other nebulæ, such as the Milky Way, etc.—everywhere dependence manifesting only extended continuity.

Are we now then to believe that here the continuity of gravitation is suddenly and absolutely fractured, and that nebulæ are not united by the same connecting influence with other nebulæ, and the whole material universe hung together in one continuous bond of mutual attraction; but that each nebula stands insulated by itself, having its own measure of gravitation confined strictly to its own surrounding area, and having no connection with the gravitation pervading the areas of other nebulæ around it? We are aware this question is too great for definitive or absolute physical solution within the existing limits of our observation and knowledge, but it may not be always so. We have found even the nebulæ to be variable as well as the stars; may we not then yet be able to discover that the variability of separated nebulæ has some reference to their action on each other? for it is for that purpose we suggest the line of observation and inquiry which the question implies. Experience makes us acquainted with no fracture or interruption in the continuity of gravitation up to this point; and its voice, therefore, taken as the utterance of all analogy on the subject, is that there can be no interruption here. This, at least, is certain, that the great disposing Power which has distributed these nebulæ through space, and placed them so remote from each other, must have been conscious of the respective gravitations of each, and purposely secured any amount of insulation that exists with the specific view of avoiding the confusion and collision which would have resulted from their closer proximity; and that this supreme Power must therefore possess a combined and unifying sway over all. Thus, the personal unity of that Power, its wisdom and its immensity, are demonstrated by the great facts and phenomena of this imperial science, and thus mightily, impressively, and supremely, above all other witnesses, do the heavens declare the unity, the personality, and the glory of God! Our question, therefore, put, as it is, on a purely scientific basis, develops in answer to it one truth, above all—great, and clear, and irresistible, even where it fails to educe another,—and that which it does enable us to reach and obtain is, fortunately for our highest intelligence, the paramount truth of the two.

But one of the most striking and wonderful characteristics which the evidence of astronomical science everywhere demonstrates in this stage of its development is its confirmation of all those great and vital principles of Christian revelation which no other religion or philosophy prevalent among mankind has recognized or asserted, or made the basis of its integrity in the same degree. The idea of one supreme and absolutely illimitable or omnipotent Power is rejected by all religions and philosophies which have not plagiarised the idea from revelation, or retained it from the early fathers of mankind, to whom the revelation was personal before it became a sacred record. But here this great truth is demonstrated by astronomy, in confirmation of the sacred volume, in so unqualified and irresistible a manner that the proof to every capable or intelligent mind must be utterly overwhelming. The next great truth so clearly indicated by the whole statements and context and scope of revelation, that life is not material, but separable from the body, is demonstrated by the evidence that the great, illimitable, and intelligent Power which rules over and distributes the heavenly bodies, exercises His power and will without there being any continuous matter co-extensive with His own personal but invisible ubiquity. The evidence clearly is, that His life does not consist of a material substance, otherwise that material substance would be continuously co-extensive with the exercise of His will, and would form an essential and inseparable portion of His power. There is therefore no such thing as a *substance of life* in a material sense in the self-existence of the Creator, nor does matter in any degree appear to be a portion or an element of His existence; for no substance we can comprehend is co-extensive with His power as the conceivable impersonation of His omnipresent intelligence. All the great characteristic perfections or attributes of God are essentially metaphysical, or, as it is expressed in revelation, *Spiritual*, and not tangible, or to any extent chemically elementary; and we are not therefore warranted in assuming or inferring that any vitality given by Him to His creatures is material, or consists in that sense of *substance*. In like manner, all the revealed ideas associated with eternity and infinitude and omnipotence have their corroboration in the infinitude of space and co-extended power, and the absolute inconceivability by the human mind of any limit to endurance, extension, and action.

Indeed, though some of our estimated distances in preceding chapters between orbits and centres of motion, and star systems and star systems, extended through ranges from those of the nearest and first magnitude to those most remote and faintly discernible to resolving power, or those still greater distances beyond all these, by which we feebly endeavour to estimate the density of the star strata, with nebulous and irresolvable backgrounds, and come at last to all that our highest telescopes can reach as mere glimmerings and phantasms in the remotest depth of immeasurable space, presenting mere nebulous irresolvability to begin with, stretching backward from us in vague and untraceable dimness into the far womb of utterly unknown yawning infinitude—though some of the estimated distances and standards by which we have endeavoured to give the reader aid in conceiving a faint idea of all these may have appeared exaggerated and extreme—a little reflection will show that the real difficulty is to be extreme, or even up to the great truths of this interminable immensity; for had the highest measurement or estimate we have given been multiplied millions of millions of times, who dare say that, at even that far stretch of distance outward from us, there is no such thing as space—no such thing as matter—no light—no motion—no form? that there, or long before reaching that point, space had ended—Power had failed—infinitude had broken down? It is only as we proceed outward that limitation becomes less and less conceivable or apparently possible. To bound a small space seems easy, though not to bound all space in or by it; but the bounding of wide and inaccessible space appears increasingly difficult, and as it stretches outward and still outward the idea of its being enclosed by a boundary becomes more and more impossible. Nay, we can form no conception of the shape of space; for, had it a conceivable shape, that shape would as a corollary present our minds with the idea of its conceivable boundary. Another feature of the question is, that we do not know of anything that could form the boundary of space. The distribution of matter through space is not in such a proportion as to be sufficient for the formation of a boundary to its widest known range, even were the matter spread out ever so thinly for the purpose. Let the presumed matter of *α* Centauri and that of the solar system be taken for an example, and it would be found on calculation that the whole material elements of both combined would not form even ever so attenuated a layer of matter extensive enough to cover a circular area of the diameter of the space intermediate between them. It is true in the remoter regions of space we perceive stars optically crowded together as closely as grains of sand, and were our optical power sufficiently intense to penetrate the distance, we should probably find an accumulation of stars just as dense and crowded in every direction in which we could look around us, and should thus have optically or apparently such a boundary universally presented as the optical limit or boundary of all space. In fact, its ultimate boundary to human science is in all probability a universally distributed and dense stratum of nebulous and irresolvable stars, hemming in the distance at every point to which the telescope can turn, and possibly enough such may be the ultimate and startling phenomenon awaiting the last and highest development of telescopic power—a universal haze of distant luminosity palely seen through dense strata and clusters of fully resolved and intervening suns. But what would be the state of the actual fact, even were such an apparent space-boundary already reached? It would not be that this optical boundary was a solid, continuous, and real one, but simply that every element of these star nebulæ, every sand-grain of the apparent stratum, though forming the universally irresolvable background to our optical power, would be on an average not less than 21,000,000,000,000 miles apart from its nearest companions, and that the diameter of each individual star did not occupy more than a twenty-eight-millionth part of the diameter of this intervening distance between star and star; so that throughout all the rest of it the widening areas of infinitude would be found passing universally through this great optically illusive boundary we had conceived to be impassable, leaving instead of a dense stratum of stars obstructing and blocking up its way, only a widely separated and faint glimmering of fractured and far-scattered starlight dimly illuminating the mighty gulf, like a few glow-worms on the lap of an immense horizon-filling plain! and no more, therefore, a boundary or obstruction in reality than the flight of a few birds across the sky are a boundary to the wide heavens or to the diffusive light of noon!

Here, indeed, if capable of teaching, we must learn in its deepest impressiveness the humbling lesson of the Patriarch, "Look unto the heavens, and see and behold the clouds which are higher than thou. If thou sinnest, what doest thou against God? or if thy transgressions be multiplied, what doest thou unto Him? If thou be righteous, what givest thou Him? or what receiveth He at thine hand? Thy wickedness may hurt a man as thou art, and thy righteousness *may* (by Divine permission) profit the son of man."

Such then is the extent, in some degree, conceivable by us of the mighty universe, among whose minutest fragments and atoms is that evanescent and vain creature of a day—that emblem of a vision—Man! Such a few of the probable aspects and arrangements, optical and real, of creation's ever-stretching and interminable ranges. The generations of humanity grow up hopeful and keen, and fevered with the restless passions and vain-glorious ambitions of life. They sow the wind, and reap the whirlwind with furrowing brows, dimmed eyes, and whitening hair. Oblivion thrusts its sickle among them. The sepulchral earth beneath their feet cries, Give. It is answered by the return of dumb ashes to the dust. The vain monument prates like a dotard and an imbecile of immortality, and becomes itself in turn time-fretted and speechless—a mockery only of forgetfulness! And so the graves of nations are filled up, and empires pass away. But the beaming orbs we have been contemplating, bright with the undimmed lustre and glory of their youth, still sing their matin anthem to their God; for it will be millions of years before many of them can complete the first circuit of their mighty orbits—before the first hour of eternity on their great star dials will have been struck—before the great Memnonium of the universe will have been thrilled to rapturous utterance with the trembling roseate of the first great dawn. Primeval eternity and dimly dawning futurity, the faintly heralded hope of that eternity before us, is all we yet know. What will be the blaze of its full noon? the quenchless glory of its never-wearying day? What will be the full revelation of that infinitude we vainly strive to search and fathom now? By what inconceivable accession of power shall we be able to perceive and know it all, and weave our expanded soul-light and intelligence throughout its vastness? The soul's desire is in the inquiry; but nature tells us we must first go to the great resting-bed of our race—that our sleep will be long, and deep, and dreamless—and that when we awake in another and a brighter dawn than we have yet seen, then we may again be privileged to ask and—to know!

Yet even now we find that the straining and eager imagination, the unsatisfied curiosity of man, by just such questions, passes the utmost range of conceivability, and stretches outward far beyond all the known and the knowable of material science in grasping thus at the infinite and the undefinable, and endeavouring to realize and comprehend them. To the mental power it is as nothing to pass outward and onward through the vast and interminable gulfs of far-extended external immensity, and people with fancies vain and fictitious indeed, but still with images of thought, those space-areas and regions of the illimitable which in themselves are at least undoubtedly real—whatever be the arrangement of matter, or spirit, or power by which they are occupied and controlled, and from which no beam of truth reaches us, no fact emanates, but the certainty that they *are*, and that they form portions of the great empire of the Omnipotent! And still we can continue to imagine onward and onward, and feel no obstruction to the energy and progress of our thought; for that which we cannot comprehend after all is not the idea of interminable extension of perpetual and unimpeded progression; not the idea that we can leave system after system, nebula after nebula, space-area after space-area optically bounded by universally surrounding irresolvable backgrounds of nebulous matter; not the idea that we can leave all these myriads of times repeated far behind, and still feel the thought's path unimpeded, and visions fresh and new and vague in ever-dawning distance, hurrying up from outward space, and passing us with electric speed as still the lightning flash of thought sweeps on The true difficulty is to conceive an impassable barrier, a limit and final conclusion, a something which the mind cannot overleap or burst through, to claim fresh dawn and distance still beyond it. It is altogether a mistake, therefore, to say, as is so often and with feebly reiterated acquiescence done, that we can form no idea or conception of the value of long lines of figures such as we have given frequently in the preceding pages of the present work, and that quadrillions and quintillions of miles are unsuggestive of thought. Such utterances proceed from a total under-estimate of the mental power and forces, and the aspirations of our moral and spiritual being. We are aware of no definable truth which the imagination may not surpass, and even make a mere stepping-stone to myriads of repetitions and varieties of it, and no imagination even which may not be used in the same way. All the higher intuitions of our being transcend the limits of all known or yet conceivable truth, and stretch forth and over them into the unknown—with wide-spread tantaculæ of desires and questionings and empirical fathoming and sounding lines searching for a final but yet unaccorded satisfaction, of which our very discontent and weariness and *ennui* are witnesses. Vast as the subject of astronomy we have just dealt with is, man's mental powers even now and in this life are greater than all these physical surroundings, mighty and majestic though they be; and his difficulty is not so much to understand them as to find means adequate to his capacity for their accurate examination—while his nobler aspirations clearly transcend them all; and though there may be many who entertain the sentiment that among present circumstances, and within the limits of the experienced and the known, they could be content to spend an immortality, and quench all the higher wants of nature before the coward thought which makes us rather choose those ills we have than flee to others that we know not of,—yet even to them it is impossible at all times to sustain the sentiment, or to avoid partaking in some measure of that higher intuition of others whose consciousness is based on the unsuppressed feelings and requirements of their being—that so long as a pure and genuine aspiration of humanity quivers unanswered on the great altar of God—a want, and therefore a prayer—so long will man be conscious that he has not yet attained to the fulness of perfection—that he is still in the outer darkness of Divine exclusion, awaiting the Master's will—that the stature of his immortality is incomplete!

We are at present, it is true, in the region of matter, and science supplies the means of exploring it. But we have a moral as well as a material nature to satisfy. And, high above all the material, the fully awakened heart in the energy of its regeneration claims to transcend the grandest and noblest achievements of science, to find communion with some lasting fountain of faithfulness in the region of sympathy, calculated to satisfy the deeper requirements of our suffering being, and exercise our baffled passion for the beautiful, the loving, the pure, and the good; and that fountain, yearned for by the whole religion of our nature, is to be found in the fulness of its perfection only where all beauty, all love, all goodness and purity supremely and inherently reside—in the great heart and sacred person of our God. All our highest consciousness of requirement candidly interpreted thus yields spontaneous homage to Him who is the perfection of beauty, robed in everlasting glory—who alone wears and alone is worthy to wear the radiant Diadem of the Universe, and hold for ever in His sacred grasp the mighty Sceptre of OMNIPOTENCE.

PART II.

COMETS.

CHAPTER XI.

The Comets—Rapidity and force of their Motions—Parabolic and Hyperbolic Comets—Nuclei, Tails, and variability of Comets—Coloured Comets—Different heliocentric attraction of the various parts of Comets—Comet in contact with Jupiter and his Satellites—Destruction and division of Comets—Lexell's—Biela's or Gambart's—Aurora in the Tails of Comets—Comets in contact with the Earth—Chemical peculiarities of Comets—Donati's Comet—Encke's Comet—Contraction of its Orbit—Liberation of Comets from their Orbits.

In the first part of the present work we have treated more particularly of the fixed stars as they are called, and the nebulæ and sideral arrangements, and star spaces external to our own solar system, with the view of giving the reader at the outset as comprehensive an impression as we could of the immensity and grandeur of the subject. But the solar system itself is not without intense interest and importance; and though its limits are small compared with those of other sideral systems on which attention has been already concentrated, neither its facts nor its features form any mere insignificant anti-climax to the immensities we have been dealing with. Its intricate and complicated motions, its forms, its exceptions, its minutely ascertained and known facts and laws, valuable and of the highest practical importance in themselves, will all tend to throw the light of analogy upon the greater sideral systems also; and we may be tempted again and again in the course of our succeeding remarks so to apply them to the greater subject as a means of more completely illustrating and impressing their comprehensiveness and value, and throwing outward from them whatever of illuminating truth they are qualified to give to the vagueness of that infinitude in which we have hitherto been in some measure merely groping, with, in all probability, only a faint glimmering of the light which special and superadded analogies may be found qualified to give us.

Let us turn attention then, in the first place, to what may in some respect be considered the connecting link between our own system and the adjacent star systems around us—the COMETS. [Many of these erratic bodies are suspected to have parabolic and hyperbolic paths in space which never return into themselves, and, consequently, do not form what are called shut orbits or ellipses of any kind; and such exceptional comets, which are very numerous, are suspected, with good reason, to be wandering visitors of many more sideral systems than that of our own sun. Such comets, therefore, are not periodical visitors to us, and many of them may possibly never visit any single system more than once. In their case it may be said that their projectile impulse or tangential motion is paramount to and in excess of the gravitation or attraction of the sun or any body they come in proximate or actual contact with; for, as we shall have immediately to show, comets do sometimes come into actual contact with other bodies, such as the solar planets and satellites. The immense rapidity and force with which such comets proceed, therefore, may be in some measure estimated by a comparison between them and the comet (I) of 1811, discovered by M. Flaugergues, on 26th March of that year. This comet has an elliptical orbit, which extends outward from our system upwards of 40,000,000,000 miles, or about fourteen times as far as Neptune, and requires, according to Argelander 3,065 years to traverse this mighty ellipse] The extent of the sun's range of attraction may thus be conceived on the one hand, and on the other the velocity and projectile force of a parabolic comet, which passes right out beyond this distance, and frees itself from the fetters of restraining or retaining solar attraction, plunging direct onward into external space. (At such a point it is not conceivable that such a comet has any curvature in its path, for curvature is the result of gravitation balancing tangential direction; but here the gravitation may be considered neutralised, and the tangential force to be the only impulse of motion]; which would therefore pass onward in a straight and undeflected line till it reached the region of some other system whose gravitation, if transverse to it, or at an angle differing from its path, as it probably always would be, would operate upon it as a deflecting influence again.

The gravitation of all bodies with which comets come into proximity has a tendency to be either transverse or angular to the path of the comet, from the fact that such bodies are in motion in their orbits as well as the comet itself. Still this gravitation would not and does not always produce an orbitual motion in the comet, as we find from the collision between Biela's comet and the satellites of Jupiter, which we shall have occasion more fully to refer to imdiately. The immense force and rapidity with which such bodies traverse space, and the irregularity of their motions—where their volume is of any great density, and their chemical components of a character to affect materially the balance of chemistry prevailing in the atmosphere and life-supporting arrangements of a world like our own—are therefore, no doubt, sources of possible danger to us; and would be causes of the most serious alarm could we believe that they were at all beyond the control of that great Power from whom our own existence is derived, or capable of acting at enmity with His arrangements and will. A question, however, of considerable astronomical importance arises as to the motions of those comets which we have perhaps somewhat hastily assumed have only parabolic and hyperbolic paths. We have already seen, on very high authority, that the sun has a proper motion, and that he is suspected to perform an orbit round a great distant centre in the direction and region of the Pleiades. The gravitation by which this proper and orbitual motion of the sun is influenced and controlled must extend from that centre outward far beyond the sun. May not then what we call parabolic and hyperbolic comets be comets having a proper orbitual motion with reference to this great centre as well as the sun himself? and may not what we have found to be parabolas and hyperbolas be so only with reference to the sun's limited area of attraction, but be after all proper elongated cometary ellipses or orbits with reference to that greater area of attraction round the centre of which the sun also moves? In dealing with such immense facts there is always a difficulty; for it frequently happens that the whole truth is beyond the range of our knowledge, or, as yet, possible observation. This doubt, at all events, appears to be suspended over the paths of the parabolic and hyperbolic comets; and it is proper that it should be stated; for, as has been already remarked in a previous passage, there is no astronomical motion with which we are *fully* acquainted which is not elliptical and orbitual. Analogy, therefore, so far as it has anything definitively to say on this subject, is in favour of the idea that these comets are not exceptions to the otherwise universal law; and if comets perform ellipses round the sun regularly and periodically, as we find they do, and belong as strictly to the solar system as its planets and satellites, why may not there be comets also which belong to that greater centre of attraction in reference to which the sun himself is only a secondary, or a luminous planet so to speak, or possibly to that great annulus of self-balancing stars, the Milky Way, of which our system is so insignificant a portion, if that annulus have a different common centre from that of the sun's suspected orbit round Alcyone (η Tauri) in the Pleiades?

We have already referred to the chemistry of comets, and the difficulty we have in obtaining any satisfactory result from the analysis of their spectra. There are other facts, however, of a marked and conspicuous character connected with them which do not leave us altogether in the dark on this interesting subject. Of these their shape is one very distinctive feature. Their known proximity to and actual collision with other members of the solar system is also important, and their self-division and changes under varying circumstances furnish additional elements to the consideration of their chemical composition.

Some of the comets are apparently composed of entirely vaporous matter; their densest parts, even at what is called "the head" or concentrated nucleus, being so rare as to allow the faintest stars to be distinctly seen through them when they happen to be interposed between us and such objects; and the tails being, in every instance where they are furnished with that appendage, also of that extreme transparency. Other comets, however, are not without very considerable density of body. The nucleus of Donati's celebrated comet, seen in 1858, was 5,600 miles in diameter—more than two-thirds the diameter of the earth—and, computed according to M. Faye, to have had the weight of a sea forty thousand square miles in superficial extent, and a hundred and nine yards deep. The above was the diameter of the nucleus on July 19th, 1858. On August 30th the diameter was reduced to 4,660 miles, and the tail had then an extension of 14,000,000 miles. On September 23rd the diameter of the nucleus was further reduced to 1,280 miles, and the extension of the tail to 12,000,000 miles. On October 5th its diameter was 400, and the extension of tail 33,000,000 miles; and on October

10th the diameter of its nucleus was 630 miles, and the extension of its tail 57,000,000 miles. Its shape and proportions, therefore, were continually varying, and sometimes with the remarkable phenomenon of a contraction both in the nucleus and in the tail, sometimes with a contraction of the nucleus and an extension of the tail. These phenomena, however, are by no means exceptionable with regard to comets which frequently appear without tails altogether, while at other times the same comet will appear with a tail. The reader must not, therefore, suppose when the appearance of a comet is presented to him in an astronomical illustration that he is looking on its characteristic or prevailing far less its permanent appearance, but only upon its purely transient aspect at the time when the particular observation of it represented was made. Some comets have neither nucleus nor tail, but appear to be a mere mass of homogeneous vapour of equal density or tenuity throughout. Others are characterized by a nucleus, with that surrounding hairy-like fringe or brilliancy which first gave name to these bodies from Coma, *hair*. They also sometimes exhibit, in addition to their other peculiarities, the beautiful phenomenon of colour. The comet of 1811, already referred to, was observed by Sir William Herschel to have a ruddy coloured nucleus, surrounded by a bluish green tint. Another feature is the forms and numbers of their tails, and the variation of them from time to time. The tail is frequently in a direction opposite to the sun; but it is at the same time so frequently of a curved form that there is no reason for assuming this circumstance to arise either from solar influence or from the effect of any obstruction the comet encounters in passing through any medium opposing its progress in universal space. The head is not always of a round or spherical shape, but it is sometimes rounded, sometimes radiated, and sometimes oval; and where a nucleus is distinct, it is generally found, according to the observation of M. Arago, to be toward the side of the surrounding nebulous matter nearest to the sun, and not in the exact centre of the volume; as if indicating that the denser part was more subject to solar attraction than the thinner portions. It has been stated also that comets decrease in splendour in each successive revolution round the sun; and it has been observed that they have a tendency to contract in volume as they approach the sun, and to expand as they recede from him again. Whether they are self-luminous or are revealed to us by the reflection of solar light has not yet been definitively ascertained. The fact, however, that the centre of the tail generally appears dark, as if the head, from the position it occupies in the extremity nearest to the sun threw a shadow into it, would almost indicate that they are not self-luminous.

Another set of remarkable facts connected with these bodies is, that even where they come into actual contact with other members of the solar system they do not appear to exert any influence upon them, though apparently very powerfully acted upon themselves. Thus Lexell's comet became, at its appearance in 1770, entangled among Jupiter's satellites, and does not appear to have been able to free itself from their influence for a period of some months. Yet it does not seem to have exerted the slightest appreciable influence upon the satellites of Jupiter, or upon Jupiter himself. This comet has received the name of Lexell's lost comet, because while he had calculated the period of its next return, and found that the ellipticity of its orbit gave it five and a half years, it has never reappeared since 1779, in consequence of its path having been wholly changed by a second contact with the body of Jupiter in that year, which so deranged its motion that it has never been capable of identification as the same comet; the means of identification being, as we have indicated, not anything permanent in the aspect of the comet itself—for that is constantly changing—but in the identity of its orbit only; which in this case was completely destroyed by alteration. Instances also of the separation of a comet into two parts have now been well established. A double nucleus was observed in a comet seen in Brazil by Liais, in 1860. But the most remarkable of this class is Biela's, otherwise called Gambart's comet, which was ascertained to have a period of six and a half years, and at first appeared very small and with an almost circular nebulosity, but without any tail. In 1846 this comet was seen to divide into two parts. At its return in 1852 the distance between the two parts had increased to one and a fourth million of miles, and was considered to be permanently established and complete. In 1859 the comet was not observed from the unfavourable position it occupied, and in 1866 it seems to have entirely disappeared. One of the remarkable characteristics of its division is, that while this comet was a nebulous and almost concentric body to the earlier observations of it in 1845, it became subsequently elongated; and, after its separation, each portion of it had a tail.

Astronomical evidence of very high authority is unfortunately at conflict as to whether comets have ever exhibited phases such as that exhibited by the moon during the period of her waxing from the crescent to the full moon, or waning again. These appearances, if they could be established, would undoubtedly prove that comets shine only by reflected light; but the absence of phases would not prove, on the other hand, that they are self-luminous bodies, for it is hardly conceivable that such thin and translucent matter as they appear to be composed of should be dense enough to exhibit a crescent or other phase, and much more reliable and characteristic evidence in this direction appears to be furnished by the dark interior of the tail already mentioned. Another of the peculiarities of cometary matter is, that in cases where comets have had multiple tails, one of the tails has sometimes extended in the direction of the sun. In contradistinction to the theory that the nucleus throws a shadow through the tail, it is suggested that the tails are in many instances hollow, and sometimes conical or trumpet-shaped cylinders; and that the darkness of the interior is accounted for in this way. The vibration of the tails of some of the greater comets is also a remarkable phenomenon. Beginning at the head, these vibrations traverse the tail to its extremity with great rapidity, similar to what may sometimes be seen in the Aurora Borealis. Olbers has endeavoured to give some explanation of this; but the peculiar modifications which many recently observed comets undergo in the development and contraction of the whole mass of the tail, as well as of the nucleus, will leave it doubtful whether there be not chemical action in these bodies of very great and varying activity, which has more to do with this appearance than we can yet precisely determine.

These various characteristics of comets are highly suggestive in one way, for they appear to demonstrate most conclusively the distinctive character of their chemistry, and that their elements, whatever they may be, are not at all identical with any chemical element with which terrestrial science is acquainted. It is stated, upon what must be considered as very reliable authority, that this world must have passed through the tail of the comet of 1861 on the evening of 30th June of that year, and it has been also stated that a phosphorescent mist was observed about the same time, which might have been a consequence of it. Arago has also put the question whether the extraordinary mists which in 1783 and 1831 covered a large part of our continent, may have been the result of such an admixture as the vaporous particles belonging to comets with the terrestrial atmosphere. But it is hardly probable that the effect of such an admixture should be confined to a single continent, and it appears perfectly certain that the phosphorescent mist of 1861 could not have been occasioned by anything like an extensive introduction of new and additional phosphorous into the earth's atmosphere, otherwise its chemical effects would have been much more striking and impressive than a luminous mist. Whatever addition such a contact might make to the amount of the earth's actual and existing chemistry, would produce unmistakable effects of a much more decided character than a mere transient mist; and if there were really any chemical identity and consequent chemical affinity between the matter of comets and the matter of the earth, it is not conceivable that we should pass through the tail of a comet without withdrawing a large portion of its matter from it, and making a permanent acquisition of it to the volume of some of our own elements, the effect of which might be a serious derangement of the existing balance of terrestrial matter. Astronomy, therefore, must not speculate in this direction without taking chemistry hand in hand.

We consider, then, on the authority of chemical science, conjoined with the peculiarities of comets already detailed, that the matter of comets is not identical with any of the earth's chemical elements, and the further we consider these peculiarities the more this becomes apparent. For example, the matter of comets is not possessed of concentric attraction, even with reference to itself, neither is it possessed of chemical affinity for itself. This is fully established by the eccentric forms of comets, and their capricious variations of shape and size; and still more so by the absolute separation of comets, such as Biela's, into two distinct and non-cohering parts; which has demonstrated that there is such a kind of matter in some, if not all, of these comets as is possessed neither of cohesion nor concentric attraction in itself, although at the same time, and most conflictingly, subject to solar and planetary attraction; for how they should travel in an orbit, and yet reject the laws of chemical affinity, mechanical adhesion, or concentric arrangement, is a condition of things not conceivable of any terrestrial element or compound. We cannot, therefore, help concluding, that in case of our actual contact with any of these bodies, their chemistry would prove absolutely nugatory and innocuous to us. Again, their luminosity, if they possess any in themselves, cannot be of the nature of combustion, but something similar perhaps to phosphorous, but still not phosphorous. Their form is not at all in accordance with anything to which combustion can be reconciled; and the development of their trains or tails does not harmonise with any of the phenomena of combustion, or with any equilibrial distribution of temperature through any homogeneous body, elementary or compound. Their whole aspect, indeed, is, in these particulars, a radical contradiction to all chemical experience and all known chemical laws. Their contraction under the influence of heat also, as they approach the sun, and their expansion as they recede from him, is at variance with all our chemical laws as applied to any kind of visible vapour such as they seem to be composed of. Were they higher in temperature than the sun—which is not conceivable, and not in accordance with our experience of them when in proximity with us—we might suppose that their contraction was occasioned by his withdrawing a portion of their heat. Yet why should they part with it only to him, if that were so, and not to cooler space all round them when at a distance from him? The phenomenon will not yield an explanation of itself to any logical test we can apply to it, but it would at least appear to prove that there is no combustion in them; otherwise their approach to the sun would co-operate with it in expanding them, and not operate as a contracting cause. Yet chemical they must be, and in a state of great chemical activity of some kind, as the following facts regarding Donati's comet at its last appearance, and some others, will sufficiently show. This comet, at its apparition in 1858, was more carefully noticed than any one previous to that date had been, and the monograph on it of Professor Bond is an invaluable addition to our cometary knowledge. In August, 1858, it had become visible to the naked eye. Some time after this it underwent most remarkable changes. After September 15th the limiting surface of its head had a close resemblance to a surface or figure generated by that geometrical line called a catenary revolving on its axis. Seven distinct envelopes were after this observed to be thrown outward, the later of them overtaking the first thrown out. The comet of 1861 had eleven similar envelopes thrown out. The comet of 1862 was observed by M. Chacornac to throw out thirteen similar envelopments in a period of seventeen days, by a force resembling the emission of jets of steam, the projections being on the side opposite to the tail, and directed more toward the sun. After each expulsion the ejected matter seemed to be repelled as if by the sun in the direction of the tail, towards which it then flowed. To account for these phenomena, and the other variations in the forms of comets, M. Roche has applied a theory of M. Faye's, by which the latter ascribes to the sun an attractive power over comets in virtue of his gravitation, and a repulsive power in virtue of his temperature or heat. But it is difficult to see that in the latter part of this hypothesis a condensing or concentrating power is the same as a repulsive power; and the fact that some of the tails of comets have been found directed towards the sun, and preceding the motion of the cometary nucleus, would rather show that this line of explanation is liable to grave exceptions. Indeed, the development of these envelopes would rather go to prove that the ejected matter had a greater affinity for the matter of the tail than for the matter of the head or nucleus, and that, though repelled from the nucleus in an opposite direction from the tail, in consequence of the position of the repulsive force for the time, it acquired after that a power, when the repulsive force was exhausted, to regain the position which its affinity for the matter of the tail would probably have taken to begin with had its chemical tendency been the only acting force. At all events, solar influence can hardly be said to give even the remotest suggestion as to the separation of comets into two parts, and it is difficult to conceive that solar influence can have a repulsive power over cometary matter without affecting it all equally. The solar heat may doubtless act upon it, and probably does so very powerfully * at its nearest approach to the sun, which is sometimes very close indeed; but there must after all be something very peculiar in the chemistry of the cometary matter to begin with to account for its remarkable action within itself. Even the operation under high temperature of unequally expanding gases would not account for the phenomena it exhibits; for the tendency to increased expansion does not coincide with the increase of temperature, nor is the form or direction of expansion that which any gas we know would be apt to take under any conceivable circumstances.

A singular question has arisen from a peculiarity of the comet known, from Professor Encke's careful observations of it, as Encke's comet—namely, a continually progressing contraction of its orbit round the sun, from which it is considered that at last this comet will be precipitated into and united with the body of the sun; though this may be delayed for many ages by the powerful attraction of some of the larger planets, and more particularly by that of Jupiter. This

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* Secchi mentions, from observations he made of the great comet of 1861, that at one point of its orbit its nucleus became incandescent from its proximity to the sun, and shone for some days by its own light or incandescence.

continual contraction of the orbit has not been accounted for by any calculation of its retardation by the planets, though it is known to be affected by them. It has therefore been conjectured by Professor Encke that the contraction is due to the resistance of a thin medium of ether, extending between the heavenly bodies sufficient to affect the motions of bodies of such excessive tenuity as comets, though not sufficient to affect sensibly the motions of such dense bodies as the planets or their satellites. This question, the professor carefully observes, is wholly open to conjecture, and it certainly does not appear to be quite in harmony with some of the phenomena of this comet itself. Thus it is well known that the tails of comets are more attenuated than their nuclei, yet this particular comet, which generally does not possess any tail, had, in November, 1848, a small tail turned from the sun, and a second and smaller tail turned toward him; so that it would rather appear from this fact that the thinness or tenuity of the tail, even when added to its greater extension than the nucleus, does not increase the resistance it encounters, nor give concomitant evidence of a resisting medium, otherwise it would never be possible for a comet to carry an extended tail or projection in front of it in the direction of its motion. Possibly the contraction of the orbit may in some measure be due to the contraction of the nucleus when nearest the sun, and the non-concentric nature of cometary matter, combined with the continual shifting of balance which must be taking place from the chemical activity they display, as already mentioned in reference to Donati's comet and others. It is plain that the division of Biela's comet into two must have wholly changed the original orbit in that case, and possibly from leaving the parts with less mass to be acted upon by solar attraction and the same projectile force or tangential velocity as before, caused the two parts to extend outward into space, and acquire much more enlarged orbits, or enabled them even to pass off into hyperbolas, and liberated them altogether from the permanent control of heliocentric gravitation.

In short, a volume of matter such as that of which a comet is composed—possessed at once of a power of indefinite change of form, and, so far as it is subject to the law of heliocentric gravitation or solar attraction, having thereby a power of capriciously altering the centre of its gravity at all times with reference to that attraction; a mass possessed at the same time of no concentric attraction in itself, and not even of chemical affinity nor of mechanical cohesion, as would appear from experience and observation of cometary transformations and self-divisions already explained—cannot well be calculated on as an object of regular orbitual motion; and we are rather inclined to feel surprised at the degree of regularity manifested by Encke's comet than at the variations and peculiarities it displays in the times of its orbit, and would be much more predisposed to ascribe its comparatively regular periodicity to the fact that it has in shape very little varied at any time from the condensed and accumulated form of a rounded nebulous mass with an interior nucleus; and has only exceptionally and rarely given evidence of its power to project a tail or train, and perpetrate the other caprices of this anomalous cometary chemistry.

It ought to be mentioned, however, in connection with this branch of the subject, that four of the six comets mentioned in the beginning of the next chapter as having periods of from 68 to 77 years, are suspected by some astronomers to have been originally only one comet. This is speculation from the proximity of their orbits and periods merely, and is not founded on any certain knowledge of the fact, so that as a matter of scientific accuracy it can never be taken for more than conjecture. *Indeed, we question its possibility.*

COMETS.

CHAPTER XII.

Classification of Comets—Short-period Comets—Particulars of short-period Comets—Encke's Comet as a means of correcting Laplace's estimate of the mass of the Planet Mercury, and affording Le Verrier a more accurate basis for predicating the existence of the new Planet Vulcan—De Vico's Comet—Perturbations of D'Arrest's Comet—Known periodicity and antiquity of some Comets—Ancient Apparitions of short-period Comets—Long-period Comets—Particulars of long-period Comets—The aphelion distance of some Comets compared with the distance of Neptune and of the Fixed Stars—Dimensions of the Heads and Tails of Comets.

It is somewhat difficult to divide the various comets into distinctive classes, so much are they now found to be liable to changes which may at any time run one class into another, and alter their whole distinctive character. While the liability we are under to be visited by strange and altogether unknown comets at all seasons, or by old comets or their fragments under new aspects and totally different orbitual arrangements, renders it difficult to speculate on the fixed aspects or characteristics of any of these bodies, or on their future tendency and determination. What has been *observed of particular comets* is about as much as can well be relied on. What *may be,* unless we base our speculations on given and limited conditions, it would be very hazardous to say. Were Encke's comet, now about the best observed of all—thanks to the great and indefatigable pains of the eminent professor—to divide like Biela's, or even very greatly to elongate in one direction from its nucleus, and thereby alter its centre of gravity with reference to solar attraction, we cannot well say what would be the result of such a change or modification, but it is doubtful whether the learned professor's calculations of its period and its perturbations, hitherto found so remarkably accurate and reliable, would then any longer apply. And yet we must, it is to be feared, look upon all comets as liable to these or similar contingencies, the occurrence of which no scientific foresight under our present entire ignorance of their chemistry and its laws can possibly enable us to predicate. We may, indeed, divide them into two classes, viz. :—

I. Elliptical or periodical comets, and

II. Parabolic and hyperbolic, or non-periodical comets.

And the first of these two classes we may subdivide into (1) comets having *short*, and (2) comets having *long periods*.

In the first sub-class may be included twenty comets having periods of from about $3\frac{1}{3}$ years to 77 years, viz. :—

1. Encke's
2. De Vico's
3. Pons's
4. Brorsen's
5. Biela's
6. D'Arrest's
7. Faye's
8. Méchain's
9. Lexell's
10. Blainpain's
11. Pigott's
12. Burckhardt's
13. Peters'
14. Clausen's
15. Westphal's
16. Pons's (1812)
17. De Vico's (1846)
18. Olber's
19. Brorsen's (1847)
20. Halley's.

The first seven of these comets have all periods under eight years each. The eighth has a period nearly double that time, the following six, from 9 to 14 inclusive, have not been yet sufficiently observed, but they are considered to have periods nearly as short as that preceding them. And the remaining six, from 15 to 20 inclusive, have periods ranging from about 68 to 77 years.

We have already mentioned nearly all that is peculiar to the first of the above comets (Encke's). It only remains to add with regard to it, that it received its name, not because Professor Encke was the first who observed it, but because he calculated its elements so carefully, and its retrospective as well as prospective periods with such scrupulous fidelity, that his name was attached to it by astronomers as a universal acknowledgment of the merit and ability with which he had performed some of the most tedious and intricate calculations of practical astronomy, and added to his science the triumph of determining the elements and orbit of the first comet of short period which had been ascertained. The professor further added to his laurels, in connection with this comet, by discovering that when in 1835 it passed very near to Mercury, Laplace's value of the mass of that planet was far too great, as it should, had Laplace's estimate been correct, have affected the geocentric right ascension of the comet on November 2nd, 1838, to the extent of 58′, and increased its declination to the extent of 17′. No corresponding disturbance of the comet's orbit having actually taken place, a much lower value has since been assigned to the mass of Mercury, and this correction has assumed much greater importance since then, from the accuracy with which it has enabled M. Le Verrier to calculate the position and influence of that planet, and predicate the existence of the new planet Vulcan, discovered from the perturbations of Mercury, to which allusion will be made in its proper place. Thus comets have had something more than a mere sensational or phenomenal interest in modern astronomy.

De Vico's comet, though calculated to have a period of 5·469 years, has not answered expectations by its appearances, as in three of its periods, 1855, 1861, and 1866, it could not be detected, and Le Verrier has made some computations, from which he suspects it to be identical with the comet of 1678. Biela's comet we have already remarked on very freely. Pons's and Brorsen's comets, 3 and 4 of the list above given, call for no special remark. D'Arrest's comet, No. 6, is subject to much irregularity and perturbation from the influence of Jupiter upon its orbit. Faye's comet, No. 7, discovered in 1843, has been shown by the calculations of Le Verrier to have been connected with the solar system since 1747. Its period is 7·44 years. Of all the other comets in our list, the last, Halley's (No. 20), is of the greatest historical interest, as having formed the object to which Sir Isaac Newton first applied the principles of physical investigation laid down in his *Principia*, (published shortly after its appearance and announcement by Halley in 1680,) and predicated, before discovery of periodicity in any comet, that these bodies were subject to the same laws as the planets, and performed revolutions round the sun in elliptical orbits. Halley was thereby led to investigate the fact, and after careful observation made the confirmatory discovery that his comet was identical with the comets of 1531 and 1607. Halley also, from a slight discrepancy in the intervals of the comet's return, predicated the influence of planetary perturbations on the orbits of comets, which has since been so fully confirmed by actual observation, and by the minutely accurate calculations of Professor Encke more especially. The previous appearances of this comet have been traced still further back by recent astronomers. Its apparition has been identified with a wonderful sign which appeared in the heavens in 1223, before the death of the French King Philip Augustus. Its appearance in 1066, the year of the Norman Conquest, which it has been superstitiously regarded as presaging, has also been identified both by European and Chinese records, and fourteen previous apparitions of it, extending from the Norman Conquest back to the eleventh year before the nativity of our Saviour, have all been verified by Mr. Hind.

Of the second subdivision of Class I.—*comets of long periods*—some examples of extreme interest may be cited, and one of the first things which strikes the mind is the immense gap between their periods and those we have just been considering. The longest period of those last mentioned is that of Halley's, whose next return will not be till the year 1912, its period being about $76\frac{78}{100}$ years, or say 77 years, and its aphelion or greatest distance from the sun 3,200,000,000 miles, while its nearest or perihelion distance is 56,000,000; so that the orbit of this comet is an extremely elongated ellipse, in which the sun is situated at one of the foci, as nearly as may be, in round numbers, one-sixtieth part of the length of its major axis or longest diameter from the nearest end of the orbit. That is, if the extreme length of the orbit were measured by a straight line down the centre of it, and that line divided into sixty parts, the sun would be nearly at the 59th of the 60, counting from the furthest end of the orbit, and fifty-nine sixtieths of the orbit would be extended away on one side in aphelion distance from the sun, while the remaining sixtieth part of the orbit would pass the focal point in which the sun is situated, and extend on the other side of him to the comet's perihelion distance. This is an immense elongation of orbit, as will be found on consideration, for a body which traverses the entire orbit of which this is only the largest diameter in less than 77 years. Its length outward from the sun, however, is only a six thousand six hundred and fiftieth part of the distance of the nearest fixed star *α* Centauri; and what is its orbit or period, after all, to that of one of the shortest-period comets in the following list of long-period comets, namely, a period of 13,864 years! The period of Donati's comet of 3,065 years, with its aphelion distance of 40,120,000,000 miles, is like the period and span of a child to the age of an antediluvian patriarch compared with this; and yet we have not only this comet, but the others following it, with periods vastly greater still:—

1. Comet ii., 1840 - - -	period	13,864	years.
2. Comet iii., 1847 - - -	„	13,918	„
3. Comet, 1860 - - -	„	15,864	„

4. Comet i., 1780	period	75,314 years.
5. Comet ii., 1844	„	102,050 „
6. Comet, 1744	„	122,683 „

Besides the latter of these comets, Donati's might be well ranked as a short-period comet, and yet the elongation of the orbit of Donati's comet is very remarkable, and gives it no mean place in comparison with No. 5 of the preceding list, for aphelion distance of Donati's is about one-tenth that of the comet ii. of 1844, even though the period of the latter is about thirty-four times as great as the period of Donati's. The aphelion distance of comet ii., 1844, is about 406,130,000,000 miles, or about one hundred and forty times further away than the aphelion distance of the planet Neptune, and yet it extends outward less than a fifty-second part of the distance of the nearest fixed star α Centauri; but as No. 6, the last comet on the list, has a period of about 20,000 years more than No. 5, and others may yet be discovered of still longer period, we were not far from a fair estimate when, in a previous chapter, we assumed the diameter of the sun's area of attraction to be at least one-twentieth of the distance between us and α Centauri.

We have sufficiently set forth the fact that comets are subject to continual change in their appearance and dimensions, and it only remains to note some peculiarities of the varying aspects they present. Sometimes they have but one appearance, that of a homogeneous woolly nebulous mass without any interior nucleus. Sometimes they consist of two parts, the woolly nebulous mass called the coma or head, and a nucleus or more bright and apparently condensed part within it. Some of them have, at times, an outer veil surrounding the head, and called the umhüllung; at other times they have numerous temporary envelopes thrown out beyond all these, such as we have already mentioned of Donati's and other comets in the preceding chapter. In addition to all this, many of them have a tail, or train, or number of tails, straight or curved and sabre shaped, and sometimes projected at widely different angles from each other, sometimes in diametrically opposite directions. Of course these various parts and appearances are of continually changing dimensions. It is only necessary, therefore, to mention some of the great dimensions to which the respective portions have been known to attain. One of the largest nuclei yet observed was that of the comet iii., 1845, which had a diameter of almost 8,000 miles, or equal to that of the earth. The diameter of the head or coma of the comet i., 1811, was about 1,125,000 miles, or a hundred and forty times the diameter of the earth; consequently its bulk, or the space it occupied, was about five thousand three hundred and sixty times that of the earth. It may well be conceived that if such bodies were very dense, and possessed, in proportion to their dimensions, a concentric gravitation like that of the earth, their passage would not only require a very serious amount of accommodation in space, but would occasion very great derangement to the planetary orbits of our system. This comet, in addition, had a tail at one period found to be the length of one hundred millions of miles, or many hundred times the length of the diameter of the very formidable coma or head of it just mentioned. As may be supposed, such a magnificent comet did not very soon disappear. It was five months longer in view than any other comet on record, having been visible altogether about seventeen months. The largest tail yet observed of any comet was that of comet i., 1843, which had a tail twice the length of the preceding one, or extending two hundred millions of miles. We have heard of children being amused with the nursery puzzle—how many foxes' tails would be required to reach to the moon. Here is a tail at last fit for such a feat of mensuration. But, alas, the distance of the moon (240,000 miles) would look something like the twentieth part of an inch upon a yard measure placed beside such a tail. It would stretch from the earth right onward past the sun, clear across the earth's orbit, and more than ten thousand miles beyond the other side of it. Such are the startling facts of astronomical dimensions and comparisons. This is surely, according to the children's answer, the one tail long enough!

COMETS.

CHAPTER XIII.

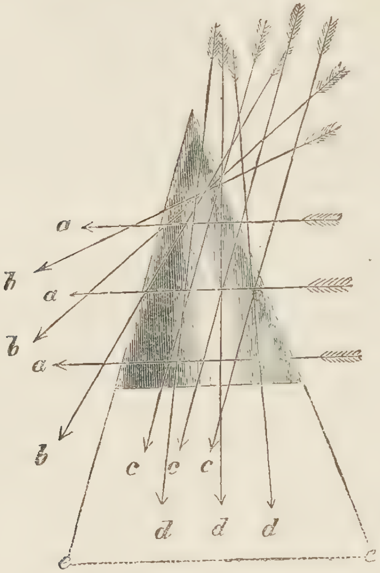
Will the long-period Comets ever complete or repeat their Orbits?—Uncertainty of the answer—Spectra of Comets, Nebulæ, and the Aurora Borealis—Parabolic and Hyperbolic Comets—Orbits and Conic Sections—Arago's Classification of Comets—Laplace's Theory of the Universe—Considerations and scientific objections—Double Orbits of the Comets and the Moon's near and further Surfaces—Formation of the Tails of Comets—The Tail an Electrical Phenomenon?—Numbers of Comets connected with our System—Invisible Comets.

THESE, then, are some of the facts with regard to the first class of comets, consisting of the two subdivisions—comets of short and long periods. We have found that these periods extend from little more than two years to the immense time of more than a hundred and twenty thousand years. Many of these bodies have repeated their orbits with great regularity, having been traced, in the case of Halley's, through a range of two thousand years of human history; but these were among what we have presumed to call short-period comets, and we venture to think that all that have been known to repeat their orbits, or that have periods shorter than those whose orbits have been repeated, may be assigned a place in this class or division. Will, on the other hand, any of the longer period comets ever repeat their orbits while the space of sublunary time endures? Will many of them ever strike even once the great cyclic hour of noon upon the vast elliptic dials of their motion? Or is the vow of prophecy before them destined to invade the regions of science long ere then—to shatter the fragile sand-glass of time, and spill its feeble grains? The question will haunt us like a melancholy spirit moaning in the night. Science, of course, will say, why should we doubt? Its facts are stable, its laws are firm-knit and strong. It cannot be possible that such things should not go on. True, so far as appearances go; but experience has told us something about threescore years and ten; and, alas! in passing along an empty midnight street we can hear its silence broken by the sharp, harsh raps of a benighted hammer busy still at work—its task, the nailing together of a little shell. Ask that lonely workman why his toil? He will likely tell you that the rosebud of some family hope has withered in an hour—that the silken lining of that little coffin which he is just arranging is but a vain solace—yet all that mother-love can do for death; though even Niobe herself were there, or Rachel drenched with weeping. Little feet totter and fail at the outset of their course. *It is not necessary—it is not an essential condition of things, that every form created should run its apparent race.*

We have more than once referred to the spectrum analysis of cometary matter. Mr. Huggins and others have made important, though not quite satisfactory, experiments and investigations of this interesting subject; and investigations have also been made of the spectra of nebulæ, as already mentioned, and of the aurora borealis. The conclusion come to at present appears to be that these several spectra give lines not capable of identification with any known substance, and that the lines of the nebulæ, aurora, and comets, all differ the one from the other. There is great difficulty about this investigation, however, and not the least, we would respectfully suggest, is whether we are not in each and all of these cases misleading ourselves by investigating, without due recognition of the fact, the spectrum of a spectrum; and whether the luminosity of comets and the aurora, as well as the fictitious luminosity attending some of the nebulæ, such as that connecting the two portions of the Dumb Bell nebula, be not that of already partially analysed or decomposed light. An examination of the *spectra* of all our already known and thoroughly established spectra (the *spectra of spectra*) might help us in this direction, though we do not venture to say that such an investigation would settle the whole question. We rather think, for several reasons, it would not. But it certainly would be one step of approximation toward that object.

The second class of comets we mentioned are those with parabolic or hyperbolic orbits, and which are therefore not periodical. Very few of these have as yet been positively ascertained. Six only can be really fixed with anything like certainty as belonging to this class, they are those of 1729, 1771, 1774, 1818 (2), 1840 (1), and 1843 (2), and the difficulty is, after all, whether their hyperbolas may not be with reference to the sun and his temporary influence only, while they may be comets of true elliptical orbits to some other and unascertained centre of their motion. Nay, it is doubtful whether, except so far as the action of solar perturbation upon them gives them a special and temporary curvature, they are either parabolas or hyperbolas, or, save within the limit of our observation, any curve of conic sections whatever. For every perturbation of a cometary path is liable to become a parabolic or hyperbolic curve according to the powers of the perturbing influence and within the range of its action; though it may only be a temporarily disturbing effect on the totally independent orbit of a totally independent body. It may be here of some consequence to the reader's correct understanding of these and other astronomical motions to give a clear and simple explanation of those conic sections to which planetary and cometary orbits and forces are referrible.

A cone may be cut in four distinct ways: 1st, transversely, as at the base, or in any direction parallel to the base, in which case the section will always display the form of a circle; 2ndly, in such an angular direction as that the plane of the section entering at the one side of the cone below the apex would pass out at the other side of the cone, in which case the section will always display the form of an ellipse or oval. And this applies to all sections at such an angle as would pass from the one side and through the other if the cone were sufficiently prolonged for the purpose, and includes all angular sections entering the one side of the cone, and less than parallel to the other side of it; and the elongation of the ellipse will be the greater the more nearly the section is to parallelism with the side of the cone opposite to its point of entrance, and *vice versâ*. 3rdly. The cone may be cut by a section entering at any part of the one side of it and running parallel with the other side of it. All such sections are parabolas, and they never form ellipses or re-entering curves, and are incapable therefore of becoming shut orbits to bodies moving in the lines of such curves; because if the cone were prolonged to infinity such a section would never pass through the side to which it is parallel, but would still continue to pass through the base at the same distance from the opposite side as that at which it entered. Lastly, the cone may be cut by a section entering the one side and passing through the base at a greater distance from the opposite side than that at which it entered, and all such sections are hyperbolas, they also never become re-entering curves, but would pass through the base of the cone were it prolonged to infinity; which shows that they also are incapable of becoming ellipses or shut orbits. These are all the modes in which a cone can be cut into sections with curved outlines or margins; for a vertical section of a cone through the apex—the only other way in which it can be cut at all—would, it is obvious, not give a curved outline, but would give straight lines forming a triangle with the base. A glance at the following diagram will explain our meaning unmistakably to the very simplest intelligence.



In the above diagram, sections in the direction of the lines *a a a* would be circular sections; in the direction of the lines *b b b* they would be elliptical sections; in the direction of the lines *c c c* they would be parabolic sections, and in the direction of the lines *d d d* they would be hyperbolic sections. All parabolic and hyperbolic sections, therefore, it must be obvious, would continue to pass through the base, even were the cone infinitely prolonged in continuation of its sides or conical expansion from the apex, as indicated by the dotted lines *e e*; while all circular and elliptical sections would pass from the one side through the opposite side were the cone infinitely prolonged, because circular and elliptical sections approach from the one side toward the other as they proceed; and parabolic and hyperbolic sections begin at the one side, but never approach the other. This little bit of geometry is extremely simple when clearly explained, and it is worth the reader's knowing, for it plays a very important practical part in the sciences. We have, therefore, been somewhat distinctive in our detail and illustration of it, and would now tender our apology to general readers for being tedious.

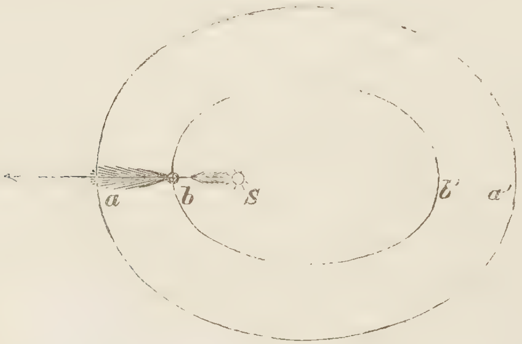
With reference to the physical condition of comets, M. Arago has made a division of them into three classes. The first class he considers to consist of round comets with planetary discs and solid and opaque bodies similar in all particulars to the planets themselves, except in the peculiar elongation of their orbits. In support of this part of his classification a remarkable incident occurred by the transit of such a comet across the sun's disc on the 18th of November, 1826, during which the body of the comet appeared not only round, but opaque and dark, to two different and widely separated observers, just as the transits of Venus and Mercury exhibit their bodies when projected against the luminosity of the solar disc. And Arago asserts there are sufficiently numerous instances of the same kind to justify his arrangement. The second class includes those comets which are translucent, and have a nucleus also translucent, even though the nucleus may be in some degree of a solid nature. And the third class consists of those comets which have no nucleus, but are composed of attenuated irregularly shaped and non-concentric matter—a class much more numerous than the other two. It is an unfortunate circumstance for the permanent value of such a classification, however, that we know so little of the physical constitution, and can rely so little on the fixity of character or conformation, of these bodies. Thus Encke's and Biela's comets would appear at times to belong to the second class, with a distinctly visible nucleus. Indeed, the latter, after its separation into two, had a head, with a nucleus and a tail, to each division of it; and at other times these two comets would appear to become entirely vaporous and exclusively of the third class. Sir John Herschel also tells us that Halley's comet in 1835, during its perihelion passage, became wholly vaporous, and there appears as yet to be no certainty that every comet is not subject to the same changes. It is worthy of remark here that all the parts of a comet are liable to self-division and separation, as illustrated by the instance of Biela's just mentioned; for if the head, the nucleus, and the tail be each of different elementary or chemical character, it is clear in this case of Biela's that the head, the nucleus, and the tail, each and all of them divided; so that it is not supposable that this division took place because the two parts into which the comet resolved itself were of different chemical materials or elements the one from the other. These minute reconsiderations of this subject are highly necessary to enable us to guard against generalizations which might otherwise be most mischievously misleading. Another peculiarity of cometary matter elucidated by the preceding facts is, that while comets generally contract and become more condensed during their perihelion passage, Halley's on its last appearance, as Sir John Herschel observes, appears to have become wholly vaporous, and to have exemplified the direct inversion of the prevailing rule.

To explain the constitution and tendency of comets, Laplace made an adaptation of the nebulous hypothesis which Sir William Herschel was tempted to propound from his first impressions of the great star nebulæ, but which was afterward rejected when increased resolving power was brought to bear upon that class of sideral phenomena. Laplace, under this theory, proceeds to explain the formation of the solar system from an originally chaotic matter; such as the comets of Arago's third class or the tails of comets may be considered as composed of. Gravitation acting upon this scattered nebulous matter begins the work of construction, according to his supposition, by condensing and attracting it toward various central points. The matter drawn toward these centres from opposite directions and at differing degrees of velocity, cause, where they meet, a rotatory motion to take place, which of course would cause the accumulated matter to acquire a circular or spherical form as the natural form of rotation. He then conceives that from this rotating mass the various planets and satellites are developed by the projectile influence of centrifugal force, which throws off portions of the matter from the surface in the direction of the plane of rotation; as—supposing that by the radiation of its heat this matter became further condensed and contracted—then the rotation would increase in velocity until the centrifugal force at its equator became too great for the retaining power of its concentric attraction. He considers that thus such a ring as that of Saturn might be formed in the first instance, and that, by the still further cooling down and concentration of the globular mass interior to it, this ring might at last become separated and left distinct in space around the body from which it proceeded. To suppose that this ring would then draw together, and become a solid body or planet, is, perhaps, not quite so obvious; and certainly the permanency of Saturn's ring, and its refusal to comply with any hypothesis on which this supposition is founded, is not encouraging as a confirmatory phenomenon. As the globe gradually contracts, however, he goes on to suppose that another and another ring might be thrown off, and another and another planet formed from the coalescing matter of it. In like manner the planets, he supposes, may from their rotation produce their satellites.

This pleasant theory has found its admirers, and some highly respectable astronomers have regarded it with sufficient favour to say of it that many circumstances exist which create something more than probability in its favour. Yet we should find many temptations to smile at the credulity of any astronomer of these times, who seriously attempted, in accordance with such a theory, to explain the formation and arrangement of the Galaxy, or any other nebulous ring, from the projectile and distributive power of a centrifugal force residing at its common centre, or at any supposable centre of such a great sideral arrangement. These theories are unfortunately all based on the tendency, so much a failing of some scientific minds, to consider matter as self-constructive and self-arranging—a fallacy which has never yet been able to discover for itself, anywhere, a basis or foundation in fact.

It is certainly true that, with the exception of the planetoids and the satellites of Uranus, the sun's axis may be considered as concentric with that of the orbits of all the planets; and that the axes of the several planets accompanied by satellites may be considered as identical with the orbitual axes of their various and respective satellites, and that the rings of Saturn have a singular conformity to the theory of Laplace. But then it is not true that any increased rapidity of rotation in the sun or in any of the planets confirms the idea of centrifugal dispersion which the theory involves as its primary requisite, and it is still less true that cometary matter shows the slightest tendency to develop itself into solar or planetary arrangements, such as the theory assumes: its general tendency is, indeed, very much the other way, and the concentration of its matter, even under temporary circumstances, does not manifest any disposition to rotate. If rotation, such as the theory supposes the sun to have at one time before it could throw off by centrifugal force such a distant mass of its matter as Neptune, for example; and if the tendency to contract were associated with a tendency to increased rapidity of rotation, it is difficult to understand on this theory how the solar rotation on its axis became so slow as it now is, and so far below the rate at which it has any power to throw off additional matter from its equator. It is also unfortunate for the theory of Laplace that the original idea of Sir William Herschel, from which it was taken, has so completely collapsed. One of the most serious objections to the theory, however, remains to be noticed; namely, the mode in which comets with immense tails, extended in the line of their radius vector or on the side of them opposite to the sun, carry these appendages round the solar focus of their orbit during their perihelion passage; and it is, perhaps, one of the most remarkable of all the phenomena connected with these singular and inexplicable bodies. Sir John Herschel, in a question which fully explains this appearance, asks: "If they (the tails) be material in that ordinarily received sense which assigns to them only inertia and attractive gravitation, where, I would ask, is the force which can carry them round in the perihelion passage of the nucleus, *in a direction pointing continually from the sun in the manner of a rigid rod* swept round by some directive power, and in contravention of all the laws of planetary motion, which would require a slower angular motion of the more remote particles, such as no attraction to the nucleus could give them, be it ever so intense? The tail of the comet of 1860, in five days after its perihelion passage, extended far beyond the earth's orbit, having in that brief interval shifted its angular position nearly 150°. Where can we find in its gravitation either to the sun or to its nucleus any cause for this extravagant sweep? But again, where are we to look, if only gravitation be admitted, for any reasonable account of its projection outward from the sun, putting its angular motion out of the question? Newton calculated that the matter composing its upper extremity quitted the nucleus only two days previous to its arriving at this enormous distance."

This phenomenon will, perhaps, be better understood by some little further illustrative detail, for it is really of very great interest. Let the reader suppose that the comet (i.), 1843, is making its perihelion passage round the sun, with a tail, as we have already mentioned, of two hundred millions of miles in length, projecting outward from its head on the side opposite to the sun—the extremity of such a tail, continuously turned directly away from the sun throughout the comet's entire orbit, must, in the course of one revolution of the comet, traverse an ellipse four hundred millions of miles longer and four hundred millions of miles broader than the elliptic orbit traversed by the head of the comet; and it must do this in the same time in which the head completes its orbital period. In short, the extremity of the tail is travelling at an immensely more rapid rate than the head of the comet, from some cause which we cannot conceive; and all the portions of the tail intermediate between its extremity and the head travel at proportionately rapid rates. The diagram will more thoroughly show our meaning.



Here the sun is in the one focus *S* of the comet's elliptic orbit. The perihelion passage is the comet's path round the end of its orbit nearest to the sun ; but, as the tail of the comet is continually turned from the sun during the whole course of the comet's revolution in its orbit, it follows that the tail reaches the point *a'* of the orbit or ellipse *a' a* as soon as the head reaches the point *b'* of the smaller ellipse *b' b*, the distance between the two ellipses being just 200,000,000 miles throughout. In short, by the time the comet's head has travelled the distance from *b* to *b'*—only one half of its orbit—the tail will have travelled in the same time, in direct line, leaving out of view the curvature of the orbit, four hundred millions of miles further than the head. The arrow we have drawn through the body of the comet may be regarded as representing the extension of the radius vector through the elongation of the cometary matter.

This sweep of the tail round a wider orbit than that traversed by the head is certainly, as the reader will perceive, a very remarkable fact. At the same time we are not quite sure, even positive as Sir John Herschel's objections seem to be, that it is wholly inconsistent with the laws of gravitation, planetary analogy, and experience, of which a more complete knowledge has been obtained since Sir John's question was written. Let us see whether we cannot elucidate an astronomical fact of some importance, at all events, even if we fail to discover a new astronomical law.

We rather think the analogy desired is to be found in the peculiarities of the moon. Like the tail of the comet, the further side of the moon performs an orbitual motion round the earth greater by just double the diameter of the moon, throughout its whole course, than the nearer side of the moon performs, and Professor Hansen has quite recently discovered from certain irregularities in the motion of the moon, that its centre of gravity is not in the centre of its apparent figure, but must be situated 1,740 miles beyond the centre of the figure, or further than the apparent centre from us; and that, consequently, while the moon presents a round disc under its transverse aspect to us, it is in reality, so far as its vertical conformation to the earth is concerned, drawn out toward us in something like a pear shape. Such a conformation would clearly explain why the moon has a fixed centre of gravity with reference to the earth's attraction, as well as to its own mass, and why it performs a revolution round its own axis only once for every time it performs an orbitual revolution round the earth. But what it shows as a coincidence with the cometary peculiarity we have just been considering is still more remarkable; viz., that its longest diameter is always in the line of its radius vector from the earth as its centre of orbitual motion—just as the longest diameter of a comet, passing through the nucleus and the tail, is in the line of the comet's radius vector from the sun as its centre of orbitual motion. Assuming roughly from the estimate of Professor Hansen, that the further surface of the pear-shaped moon, whose tapering point is drawn out toward the earth, is at the same uniform distance from the centre of its gravity as the circumference of its disc, then it would follow that the radius of the portion drawn out toward the earth is at least 1,740 miles longer than the radius extending to the surface furthest from the earth. And assuming the transverse diameter of the moon, as ascertained by recent corrections of Mr. Warren De La Rue, at about 2,153 miles, it would follow, from the calculations of Professor Hansen, that the vertical diameter of the moon, or its diameter in the line of its radius vector from us, is 1,740 miles greater than the transverse diameter, or 3,893 miles long, as compared with 2,153 miles broad; so that the diameter of the orbit described by the surface of the moon furthest from us is 7,986 miles longer and broader, or greater all round, than the orbit of the point nearest to us. Thus, taking the two concentric ellipses of the previous diagram as applicable to the nearer and further surface of the moon, instead of to the head and tail of the comet, it would follow that the further surface of the moon in travelling from *a* to *a′* would have travelled 7,986 miles further in the same time in direct line—leaving the curvature of the orbit altogether out of view—than the nearer portion of the moon had done in travelling from *b* to *b′*.

From this explanation it will be apparent that in all respects the longest diameter of the moon is kept in the same position with reference to the earth as its centre of attraction, as the line of a comet's extension is kept in with reference to the sun as the comet's centre of attraction. Now, why is the moon's longest diameter maintained in this position throughout its orbit from perihelion to aphelion distance and back? For, by ascertaining this, we rather think we approach a little more nearly to the reason why the comet's tail or line of elongation is maintained in the same position as the moon's longest diameter.

It must be obvious at once that if the moon's longest diameter were altered from this position, it would lose its balance, and that it would have to acquire a rotatory motion round its axis more frequently than once every time it completed its orbit, to compensate for its eccentric centre of gravity; and that the preponderance of its nearest radius over its furthest radius would be an impediment to this rotation. But then, it could not rotate unless its present centre of gravity, by the turning round or falling over of the body to the one side, fell nearer to the earth than it is—against which the tangential force and direction of the moon is an obvious impediment; for the tangential line of the moon's impulse passes through its present centre of gravity, and fixes its present distance from the earth at all points of its orbit.

But how does all this apply to the elongation of a comet in the line of its radius vector, from its head to the extremity of its tail? Well, with a little patience, we shall presently see. Comets, we have definitively ascertained, are subject to heliocentric or solar attraction, however little concentric attraction they may have for their own matter *inter se*. Let us assume, then, that the sun's mass has an attractive power on the *whole matter* of the comet—head and tail; and that, as M. Faye has recently propounded, the sun's *heat* has a repelling power on certain portions of the cometary matter. Supposing the nucleus of the comet to throw out a portion of its matter transversely to its radius vector, or right and left from the line of the sun's direction, how would this double power of the sun act on the projected part? Would not the sun's gravitation have a tendency to draw the projected matter out into a tail, extending in the direction of the sun? and would not, in turn, the sun's heat have a tendency to repel this projected matter in a direction opposite to the sun from the nucleus? Then, supposing that the matter were thrown out on the further side from the sun, at an angle of 45° from the line of the radius vector, would not the repulsive power of solar heat tend to correct this angular direction, and throw it into the direct line of opposition? and would not the solar gravitation, in like manner, tend to draw it toward the mass of the comet again in such a manner as to destroy the comet's centre of gravity, unless the nucleus, co-operating with the solar attraction so far, drew it back directly to itself, and thereby maintained its equilibrium? The projectile force of the comet would necessarily maintain it in its main orbit, and the orbit of the extremity of the tail would depend upon the continually changing length of the tail. But Newton's calculation, that the matter composing the upper extremity of the tail "quitted the nucleus only two days previous to its arriving at this enormous distance," comes in here with very marked importance; for it tends to show that the tail is being continually renewed and reinorced: so that, after all, the tail is not swung round in the perihelion passage like a rigid rod, but is being continually thrown out of new, or renovated in the line of the radius vector and of the repelling power—a circumstance which may go far to account for the aurora-like corruscations of the tail before referred to. Another question occurs at this point, viz., What is the cause of the curvature or sabre-like bend sometimes seen in the tail? Is this occasioned by the tendency of the comet under certain conditions to throw the matter of its tail out more slowly than at other times, and is this curve or bend backward or forward from the line of the comet's projectile force? If backward, does it arise from retardation incurred under the slowness of its projection? If forward, does it arise from centrifugal force acting on the extended radius of orbitual rotation? We do not find that astronomy has sufficiently noticed this fact to enable any conclusion either way to be come to. But from the preceding explanation, so far as regards the general question, it seems clear that a comet cannot well extend itself in any direction but its vertical diameter to the centre of its motion, any more than the moon could do, without over-balancing itself, and altering its centre of gravity, which its tangential force would obviously not allow; and that an extension of its diameter outward from its centre of gravity would naturally be liable to more increased centrifugal or tangential force from the increased radius of the orbit of the extended part: so that a combination of all these circumstances and considerations may, in some degree, be essential to a full explanation.

It seems difficult to conceive that the supposed repelling power of solar heat upon portions of the cometary matter can be a power of expansion merely, otherwise it might be expansion spherically and concentrically, just as well as expansion in one direction of elongation only. It seems much more likely that the effect of solar heat upon the cometary matter is electrical in its action, and that it renders two or more different and separable elements or compounds electrically positive and repulsive to each other, so that the repulsive force may not after all be in the solar heat, but in the matter of the comet itself, electrically excited by the solar heat. Such a force we can well conceive would not operate in the direction of spherical expansion; but the one kind of matter would keep by itself repelling the other kind of matter, which would also keep by itself directly from it; while other considerations already mentioned may account for all the peculiarities which characterise the direction of the extension or elongation. Indeed, electrical repulsion would also explain the angular dispersion of multiple tails on the principle experienced and so frequently illustrated in the case of *electrified hair*, as in that case it is easy to understand that *all the tails, being positively electrified, would be repulsive to each other;* and the whole phenomena are more characteristic of electrical than of chemical action. Electricity, too, would clearly account for the aurora-like coruscations in the tail, and their velocity; and in some degree, if not wholly, for the luminosity of the comet itself, and for that "phosphorescent" (?) mist which was observed in connection with the earth's supposed envelopment in the tail of the comet of 1861—the whole being possibly electrical luminosity only, operating exclusively on the matter of the comet's tail, which may have had no sympathy with the chemistry of our atmosphere, and may have rather surrounded than permeated or interfused itself through it.

Such then is a comprehensive view, so far, of our existing knowledge of comets. The immense number of these bodies connected with our system would render them, but for what we have seen of their influence and contact with the planets, and their chemical composition, very formidable bodies indeed; and it is still an entirely moot-point what is their object and special mission. About a century ago Lambert considered that on a moderate estimate there were about five hundred millions of them connected with our system, and within the orbit of the planet Saturn; and Arago, calculating more recently from other data, comes to the more moderate, yet sufficiently formidable conclusion, that there must be somewhere between seventeen and eighteen millions of them which traverse our system within the limits of the orbit of Neptune. Many known short-period comets are found to have their aphelion distances very near to the orbit of Jupiter, whose immense mass, compared with the other planets of our system, exerts a powerful attractive influence upon them, frequently deranging their orbits altogether, and even drawing them into collision with his satellites and himself; so that if there be anything very serious in the shock of a comet, the inhabitants of Jupiter must be pretty well accustomed to that species of nervous sensation, and possibly look upon the affair as one of their "institutions." To give an absolutely exhaustive view of bodies which, as Kepler has remarked, are as numerously scattered through space as fish in the sea, is a good deal more than astronomy can promise for many a generation to come. We are liable to new visitants of this class at all times, and in the most unexpected ways, as they come in upon our field of view from every conceivable direction; and many of them are so unfavourably situated for observation that they come and go without our knowledge, and without our consequently being able to get a view of them at all. Most comets of our system are invisible to us.

THE SUN.

CHAPTER XIV.

Our imperfect knowledge of the Sun—Recent corrections of the Sun's distance—The Sun's rotation on his axis—Solar Combustion—Sun-spots — Rice-grains, Granules, Shingle-beach — Faculæ — The Solar Photosphere; its nature—The atmospheric circulation of Solar Matter —The Sun's Luminosity—Sun-spots in relation to Terrestrial Climature —Penumbræ and periodicity of Sun-spots—Planetary influence on Sun-spots—Chromosphere and Coloured Flames—Mr. Dawes' description of Coloured Flames—Other descriptions—Hind, Lassell, Airy—The Smoke of Solar Combustion—Concurrence of Spectrum Analysis and Chemical Analogy—Eclipses, total, annular, and partial—Baily's Beads.

One little acquainted with astronomy, and the penetrating investigations of allied and collateral sciences, would be apt to think that we must be pretty well acquainted with that most important member of our system, the Sun, by this period of the world's history; yet, from various causes, this idea, if formed by any of our readers previous to their knowledge of what we are now about to state, would be a great misapprehension; and even after reading all we can say on the subject, they will find that there is much for science still to investigate, and for human curiosity to inquire after. The very oldest and most familiar characteristic of the sun, its *light*, is that which is to us one of the newest subjects of scientific discovery and increasing knowledge, and its distance and diameter have only within a very few years been more correctly ascertained than they were before. Its chemical composition also is only now coming to be partially known for the first time; while its revolution round its axis, its atmosphere, and the variations in its aspect, were all facts and features of it which before the present century may be considered to have been utterly unknown. Its proper motion, and the probability that this motion, when fully known, if we can ever hope for that, will turn out to be motion in an orbit, is a fact already referred to in these pages, which, though well established so far as the velocity of the proper motion is concerned, is yet so vague, and shrouded in the mystery of its own immensity in all other respects, as to convince the wisest of our astronomers that we have much yet to learn of the sun. Indeed, the terms photosphere (the luminous envelopment forming the sun's region of light), and chromosphere (the region of colour external to the photosphere), are expressions almost new in scientific use, and they include an immense range of subordinate and newly discovered truths.

The sun's distance from the earth has been the subject of recent reinvestigation by Le Verrier; and Mr. Stone, of the Greenwich Observatory; Ellery, of Victoria, New South Wales; Winnecke, and Hansen, have all contributed to a result which enables us with closer approximation than hitherto to say that instead of 95,000,000 miles, the sun's mean distance from the earth is more nearly 91,430,000 miles. This is the distance corrected to accord with the mean distance between the new value of the solar parallax obtained by Stone, which is 8·93″, and the parallax obtained by Le Verrier from the motions of Venus, Mars, and the moon, which is 8·95″, the mean parallax between these being 8·94″. The diameter of the sun corrected to this amended parallax is 852,584 miles, or about 107 times greater than the diameter of the earth The moon's distance from the earth is about 238,000 miles, so that the mean diameter of the moon's orbit is about 476,000 miles, or little more than half the diameter of the sun. Were the moon, therefore, revolving round the centre of the sun at the same distance at which it revolves round the centre of the earth, it would require to have a tunnel made for its orbit 376,000 miles below the surface of the sun! For the moon's distance from the earth would not reach from the centre of the sun nearer to its surface than that. This will give some idea, perhaps, of the immense size of the sun compared with the earth and its satellite.

The circumference of the sun cannot be less than 2,786,000 miles, yet the sun performs a revolution round its axis once every 25¼ days, so that its equatorial surface moves with the rapidity of 4,400 miles per hour round its axis, while the equatorial surface of the earth moves round the earth's axis with the rapidity of only 1,000 miles per hour. The centrifugal force of the sun's equatorial matter, therefore, is more than four times that of the earth in point of speed, and the concentric attraction of the sun's surface matter is less than that of the earth—the density or weight of the sun's matter at its surface being only about one-fourth that of the earth at its surface. Here then we have the singularly discrepant fact in science which we shall afterward more fully refer to in its proper place,* that the equatorial matter of the sun, with more than four times the centrifugal velocity of the earth's equatorial surface, and only about one-fourth part of the gravitation of the earth's equatorial matter, has not manifested any tendency to bulge out at the solar equator, nor shown the slightest flattening at the poles of the solar axis.

The sun exhibits every characteristic and evidence of a body enveloped in an atmosphere of flame, the lower part of his atmosphere being comparatively dark, coinciding with that portion of the flame of an ordinary candle, or other body under combustion, intervening between the brightest portion of the flame and the wick. Then comes the brightest portion of the flame, or region of white light, called the *photosphere;* and above that a region in which coloured flame or light is sometimes manifested, especially along the edges of the solar disc, and which last region is called the *chromosphere.* But for a singular peculiarity of the solar disc, however, to which great interest and attention have been of late years attracted, we should probably never have been able to discover that the solid matter of the sun was not co-extensive with its apparent dimensions or luminous appearance, or to have known, as we now definitively do, that the real body or solid mass of the sun is a dark sphere of matter confined within a fiery prison-house—a robe of fiercest flame. The peculiarity we refer to is what are popularly called the spots in the sun, an obvious misnomer, as we shall soon perceive, but a characteristic enough description of the appearance presented. These spots in the sun are, in fact, nothing other than temporary holes or rents in his fiery garment, through which his sable breast is seen, and by means of which we have been enabled to discover that a dark stratum of lower atmosphere intervenes between him and the sphere or region of his enveloping light, and that the solid matter of his body is less in dimension than his apparent luminosity. Above all other observers, the illustrious Schwabe, the astronomer of Dessau, devoted daily attention to the phenomena of these sun-spots, until, after a period of eighteen years' patient watching, revision, and verification of his conclusions, he established the fact that the spots are periodical manifestations, having their maximum and minimum development within every period of ten years. This has led to other discoveries, which we shall afterward note. In the meantime let us devote some attention to the character and appearance, as well as to the periodicity, of these "sun-spots." One of their first and most obvious characteristics is, that they pass across the disc or face in the direction of the sun's equator, and along or parallel to that belt; and when they are at or near to the centre of the solar disc, they present their widest and most open appearance to the observer; while, as they are nearer to the edge of the solar disc, in coming from or passing to the centre, they become foreshortened in their breadth, or in that diameter which is in the line in which they move across the disc. They are also liable to variations in their shape and size, resulting from an increased or diminished action of the causes which create them; but this foreshortening toward the edge of the disc, and widening at its centre, is so uniform a part of their appearance as to leave no doubt whatever that the front view of them is presented to us from the centre of the solar disc, and only a side view of them when they are passing round the edge of it, and this side view is so foreshortened as they approach the edge that, as a rule, they become invisible before they reach the edge. In addition to these spots, Nasmyth, in 1866, made the further discovery that the luminous portion of the sun's disc is not composed of light of equal or homogeneous intensity, but consists of a minutely divided series of luminous streaks, which he described as like willow leaves, round which the light is less intense, or, we should perhaps say, the photosphere is more transparent. When any of the sun-spots are contracting, or the rents in the photosphere mending, if we may so express it, he also found that these willow-leaved appearances extended from the edges of the spot across it, and formed bridges, as if *darning* or drawing its edges together. He further noted that these willow leaves did not appear to have any definite or symmetrical arrangement in the manner of their distribution across the solar disc, but appeared to cross each other in all varieties of directions, and that their average magnitude was about a thousand miles long by a hundred miles broad.

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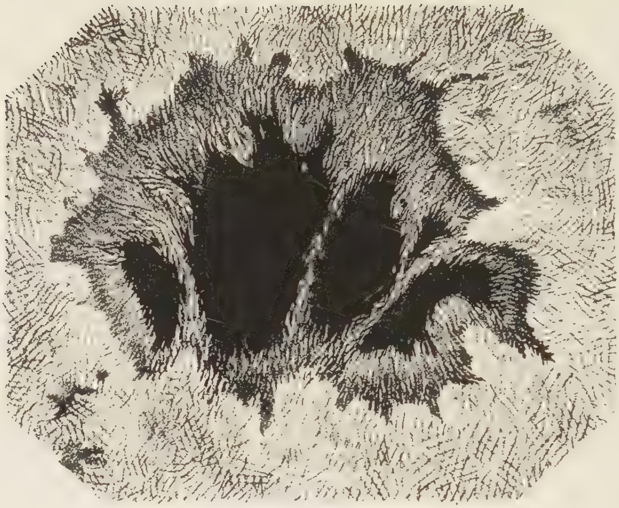
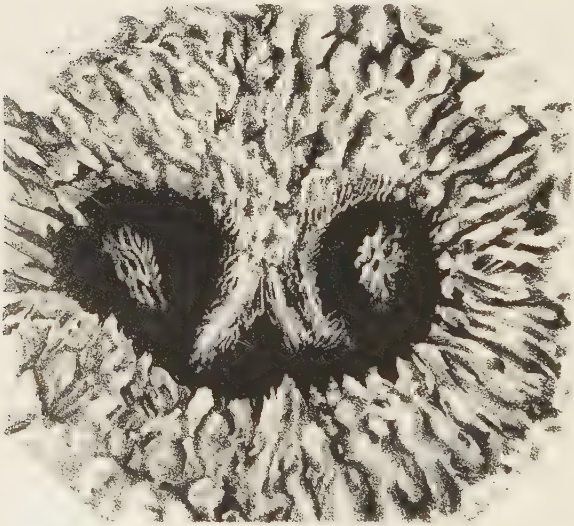
* See continuation of this subject when we come to deal with the shape of the earth, under the chapter devoted to the moon.

SUN SPOTS



Spot seen by Nasmyth. 29th July 1860



Spot seen by Secchi 20 January 1865

A good deal of controversy has encountered Mr. Nasmyth's announcement; but it may now be considered that his observations have been in the main fully substantiated, and that though the length as compared with the width of these willow-leaved appearances has been stated by some to be not ten to one, as he has mentioned, but much broader in proportion to their length; yet if they be, as we strongly suspect they are, tongues of flame forming the photosphere, and liable to continual agitation by the circulation of temperature, and of the gases undergoing combustion in the solar atmosphere, and causing continual currents to affect their form and appearance, it is quite possible they may have been of the proportions mentioned by Mr. Nasmyth at the time of his observation, and may at other times manifest the form of "granulations," "rice-grains," and "shingle-beach," which other observers have preferred as more suitable descriptive names—allowance being also made for the different telescopic powers used by each. There can be now little question that an elliptical form is the prevalent one with these appearances. Mr. Huggins has cautiously suggested the word "*granule*" as the proper form, because *no positive form* is thereby asserted. He has also remarked that they are of varying dimensions, ranging from less than one second to three seconds in length, and that they are not flat bodies, but possess considerable depth or thickness; that they are sometimes crowded closely together in irregularly shaped groups, and at other times more thinly and dispersedly scattered, giving the mottled appearance of the sun which has been long known. He further remarked that the photosphere is ridged and irregularly corrugated with heights and hollows, such as a wave-like action, of tumultuous and irregular direction, would occasion. The *faculæ*, or streaks of light which are often noticed toward the edge of the sun's equator, must not be omitted in these remarks on the appearance of the photosphere. These faculæ are irregular in their outline, and when near the edge of the disc are also nearly parallel to the edge. They appear, in fact, to undergo foreshortening like the rents or spots, and are frequently found in places where spots have recently appeared or soon afterward appear. They are brighter than the portions of the photosphere around them, and were discovered by Dawes, to be distinct projections above the general level of the photosphere, from a lucky opportunity he had of observing one passing round the edge of the disc under the axial motion of the sun.

Let us now consider the reasons for concluding as we have done that the solar photosphere is a stratum of an atmosphere full of gas in a state of combustion; and first let us state that if the luminosity of the sun were due to any other cause than combustion and flame, it is inconceivable according to any physical law of which we have knowledge how the intensely high temperature of the sun could exist *without combustion.* Its temperature would very obviously burn every solid element of our world with the manifestation of intense light and flame, and without such a result in the solar atmosphere we cannot perceive why the luminosity of the sun might not be of homogeneous and uniform intensity throughout. There is evidently in the photosphere all that undulation and motion, those projected and granulated insulations of brightness, those temporary suspensions of combustion in limited portions of the photosphere after more than usually intense light in the same place, as manifested by the preceding faculæ, which, with their brightness, seem to have exhausted the combustible resources of the locality in one great outburst of intenser temperature and more towering flame for a time—followed, after the dark and smouldering rent is darned up and bridged, by a renewal of the intenser flame of the faculæ again—as if the period of non-combustion had resulted in an accumulation of materials for a further blaze. There is all that manifestation of currents in the atmosphere affecting the shape and distribution of the "granules," "willow leaves," or "rice-grains," which would result from the circulation of unequal temperatures and the interfusion of various gases continually given out to a blazing atmosphere which we should expect to be intrinsic and associated features of a mighty orb enveloped in an ocean of flame; and such as probably enough would be manifested by our own world very rapidly if a sufficient quantity of that hydrogen which forms a great aqueous and refrigerating influence over its surface, percolating the land, and filling the ocean hollows with a drenching bath, were suddenly withdrawn. In this latter case we should find, doubtless, that the small remaining portion of hydrogen in our world, instead of being enough to form with associated oxygen a volume of water sufficient to be precipitated upon the surface of the earth, would, by the high temperature of the blazing mass of the world's unrestrained and liberated chemistry, be decomposed from its aqueous compound with oxygen gas, and, in consequence of its greater lightness—hydrogen being only one-sixteenth part of the weight of oxygen, and lighter than any element with which we are acquainted—would be floated above the compound of oxygen and nitrogen forming the present atmosphere, just as spectrum analysis tells us that hydrogen floats at present above the photosphere of the sun, forming its outer layer of surrounding gas or atmosphere, and the chromosphere in which the red or coloured flames, to which we will immediately draw attention, are manifested; and to the base or lower stratum of which, possibly enough, all the interior gases, and especially carbonic gases, require to rise before coming in contact with any volume or quantity of hydrogen essential to or present in their combustion. At such an elevation the rarified and heated hydrogen would be entirely incombustible, except in so far as it was penetrated from below by the heavier volume of underlying oxygen and other gases, and it would act probably as a means of quenching the flaming gases at a higher altitude than that at which the lower atmospheric supporters of their combustion sustained them, and of re-combining the gaseous elements into solids, and precipitating them through the photosphere back upon the solar nucleus to be re-developed into gas; just as rain is now precipitated through our atmosphere, to return to it again—after passing its period in ocean and on land—in the form of vapour and cloud. Thus it is easily supposable that the sun's manifestation of luminosity is as little a cause of waste or exhaustion to it as the earth's manifestation of cloud is to our physical system—not one atom or molecule of which is lost or exhausted by the circulation of its aqueous elements.

The sun-spots are sometimes very remarkable in shape, and Father Secchi has given one very curious face-like specimen which he observed from Rome on 20th January, 1865, and which, along with some others, will be found in the accompanying plate.

Various estimates have been given of the diameter of the sun's nucleus; but as these range most conflictingly, and are mere speculations, it is not necessary to draw any particular attention to them. Perhaps the nearest means we have of approaching to anything like accuracy on this difficult point is to observe, with greater care than has yet been done, the width to which the sun's spots extend from the one side of the solar equator to the other, as it seems but fair and reasonable to conclude that wherever darkness is seen through the spots the sable or non-luminous nucleus below is the cause of the darkness; for if at the edge of the equator the visual ray were not obstructed by an opaque body, we should be able to see the inner side of the photosphere *beyond and through* the dark but transparent stratum of atmosphere below the photosphere.

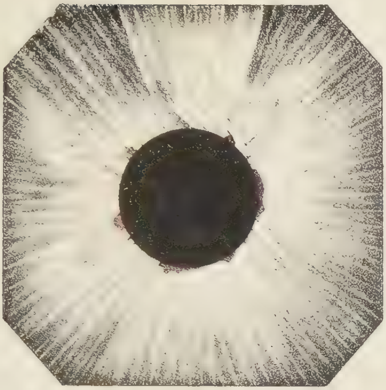
A curious contradiction appears to exist as to the effect of solar spots on the seasons of our earth, one party maintaining that recorded experience has shown the years most abundant in sun-spots to be drier and more fruitful than other years when sun spots were few; and another, from special observations made to test the fact, having come to an opposite conclusion! It is really doubtful, at present, whether we have any reliable evidence that they exercise an influence upon our seasons one way or another, and both observers may be right within the range of their observations, simply because the occurrences they have classed together may be unconnected and utterly irrelative coincidences.

During the year 1869, Father Secchi announced that the coldness experienced in Europe coincided with an unusual number of sun-spots; but, unfortunately, while this was being announced as the cause of coolness in our season, accounts were simultaneously announced in the columns of the same papers of the excessive heat experienced in Algeria and elsewhere. This announcement was obviously disastrous to the explanation suggested, as it is not conceivable that sun-spots can affect the temperature of our world in mere localities, without equally affecting its whole temperature.

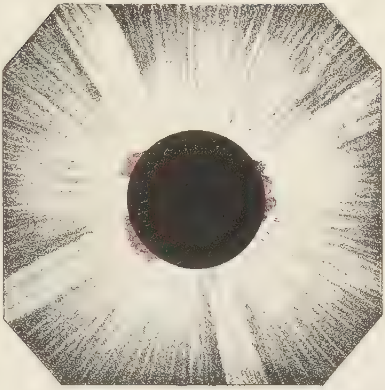
Some solar spots are found to retain their identity sufficiently to repeat their transit more than once across the solar disc, so that they continue in such cases for a longer period than thirty-eight days (a revolution and a half of the sun on his axis); and some of them have also been seen and identified for months, while others vanish in a single passage across the disc, and many are only visible for a few minutes. It will be seen by this fact that great activity prevails in the solar photosphere. Dr. Wollaston has mentioned an instance of one sun-spot observed by him, which appeared unexpectedly to burst to pieces while he was looking at it, like "a piece of ice dashed on a frozen pond, which breaks in pieces and slides on the surface in various directions." The distinguished Doctor modestly adds, "I was then a very young astronomer, but I think I may be sure of this fact." Subsequent and closer observation recently devoted to the sun-spots has fully confirmed the probability of the Doctor's accuracy. Sir John Herschel has also stated that it is not until the solar spots have assumed a considerable size that a penumbra begins to be formed, a circumstance which, he adds, strongly favours the origination of the spot in a disturbance from below acting upward, while as the spots close they leave penumbræ, which also gradually contract and disappear. This is a singular fact, and may possibly be found to be connected with, and in part explanatory of, the transmission and velocity of light when more fully considered and accounted for.

One of the results of Schwabe's discovery of the periodicity of the sun-spots has been that a coinciding periodicity, both in the maximum and minimum characteristics of the period, has been found by Laurent of Munich, General Sabine, and others, to attend the daily variation in the declination of the magnetic needle, and in the earth-currents of electricity, which affect our telegraphic system, as also in the manifestations of the aurora borealis. And Wolf has more recently announced the existence of subordinate periodicity in the solar spots connected, he considers, with the periodicity of Venus and the earth in their orbits, and that a greater activity prevails annually in the average of months from September to January. On this subject there seems no reason to doubt that the planets, by their united and several motions round the sun, must exercise upon his photosphere some such influence as the moon does upon the ocean of the world; and that tides and tidal action in some degree prevail in the distribution and density of the photosphere and solar atmosphere generally, which would affect the belt of the solar equator where the sun-spots prevail in a greater degree than they would the ate XV

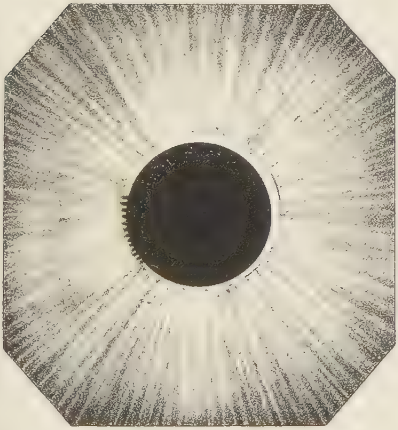
SOLAR PHENOMENA



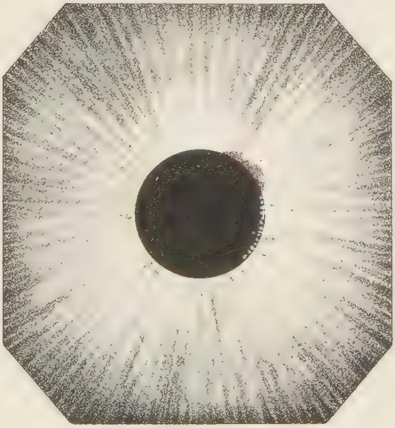
Eclipse 1858
(Liais)



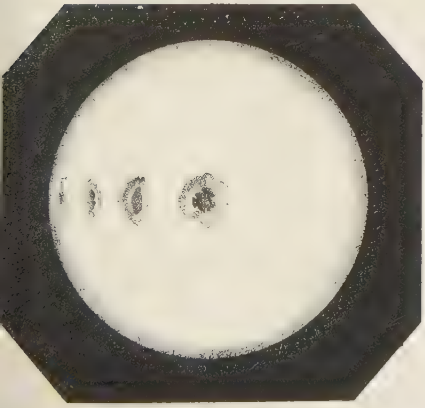
Eclipse July 1860
(Feilitzsch)



Annular Eclipse 1836
(with Baily's Beads)

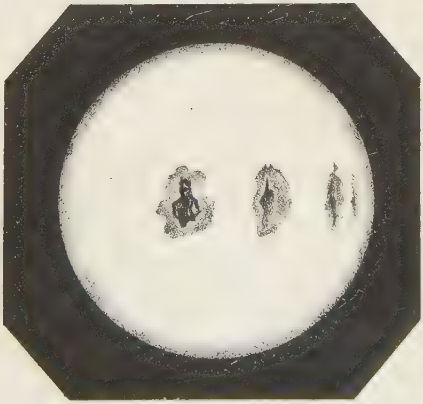


Total Eclipse 1842
(with Baily's Beads)



74.

A Sun Spot
(shewing its expansion under the Sun's axial rotation.)



A Sun Spot
(shewing its contraction under the Sun's axial rotation.)

polar regions of the sun; in which, if spots do exist, they are so comparatively small as to be invisible from their foreshortening. Such a tidal action in the photosphere when the planets are at their nearest points of general conjunction or opposition, or points of maximum attraction, would naturally draw out the photosphere farther from the body or nucleus of the sun at the portion of the disc opposed to the planetary action, and render it at the same time thinner at the sides of the disc, and thereby cause it, from the additional expansion and rarification it underwent, to be much more liable to rend and tear than at other periods, when the force of planetary attraction was less. And possibly also, when the planetary periods of conjunction and opposition, and their maximum and minimum periodicity are fully correlated with the solar phenomena, a solution may be found to the sun-spots—so far as their periodicity is concerned—which concurrently may account for the concurring periodical declination of the magnetic needle and the periodicity of the earth-currents; which, as manifestations of the electric fluid, may be both considered as one phenomenon. Of course, if this should turn out to be correct, it would still depend paramountly upon the local and temporary condition of the solar chemistry what is the extent and duration of each particular rent or spot in the photosphere, and where it is situated for the time; so that even then planetary influence will not be the sole cause. In the meanwhile, this subject is one of great interest, and in the highest degree worthy of the attention which it may be expected to receive.

A great difficulty attends these observations of the sun, as may well be supposed, from his own brilliant and intense light, and the impossibility of our bringing any telescope to bear upon his disc without having first to darken it partially, and so far consequently give a tint to the lenses through which it is viewed, which renders them almost useless for the purpose of detecting colour, if there be such a thing, in the granulæ or tongues of flame and faculæ by which the photosphere is traversed and subdivided. We might but for this expect to find each tongue of flame surrounded, like the flame of a candle, with a reddish tinted outer surface, large and intense in its colour in proportion to the size and intensity of the flame it covers—though special red flames obviously do exist, but even these it will be found from subsequent descriptions have sometimes an interior of stronger light rendering them pale in the centre. Indeed, but for the influence of eclipses in modifying and almost extinguishing solar light for the moment, we might never have discovered those red flames which are seen along the edges of the disc on such occasions, and which the interposition of pieces of darkened glass, sufficient to cover the brighter portions of the disc, and produce the effect of an artificial eclipse, are enabling us to ascertain as present at all times along the solar outlines. These flames are in what is called, from their colour, the chromosphere of the sun, or that stratum of gas which spectrum analysis informs us is hydrogen, and which envelopes the luminous disc of the sun above and around the photosphere. It is clearly impossible for us to believe that these coloured flames exist *only* along the edges of the disc, because the edge of the disc is changing continually by the sun's revolution on his axis; and we cannot doubt, therefore, that if the observer were situated at thirty-six different angles of ten degrees apart each, including the whole 360 degrees of a circle all round the sun, he would see coloured flames along the edge of every one of the whole thirty-six views or discs so presented. It must, therefore, follow that there are red flames in the centre as well as at the edge of the disc, and that these are invisible to us only from defects in our means of observation, and the fact that the brighter light of the photosphere shines clearly and transparently through them—rendering them, perhaps, invisible to telescopic view in that position, even were the eye strong enough without injury to gaze on the solar light without the intervention of a darkening medium.

These red flames were observed in 1605 by Kepler, during the partial eclipse of that year, and about the beginning of last century by Captain Stannyan, during the eclipse of 1706, and he corresponded with Flamsteed on the subject, who misinterpreted, excusably enough at that time, the cause of the phenomenon, and ascribed it to the moon having an atmosphere, which has since then, by the most careful observation of our satellite, been wholly disproved. They were also observed during the solar eclipses of 1715, 1737, 1836, 1851, and other intervening and subsequent years. A very careful description of their appearance in 1851 was given by Mr. Dawes, who states that they appeared at one point like a low ridge of red prominences, resembling the outline of a very irregular range of hills, the contour of which appeared to undulate from the west toward the east. The account of Mr. Dawes, however, is so minute, that the reader cannot form a better idea of the phenomenon, for the purpose of an accurate first impression, than by perusing his description: "Between the east and south parts," he says, "and at an angle of about 45° from the north point, appeared a large red prominence of a very regular conical form. When first seen, it might be about $1\frac{1}{2}'$ in attitude from the edge of the moon, but its length diminished as the moon advanced. The position of this protuberance may be inaccurate to a few degrees, being more hastily noticed than the others. It was of a deep rose colour, and rather paler near the middle than at the edges.

"Proceeding southward, at about 145° from the north point, commenced a long ridge of red prominences, resembling in outline the tops of a very irregular range of hills. The highest of these probably did not exceed 40″. This ridge extended through 50° or 55°, and reached, therefore, to about 197° from the north point—its base being throughout formed by the sharply defined edge of the moon. The irregularities at the top of the ridge seemed to be permanent, but they certainly appeared to undulate from the west toward the east; probably an atmospheric phenomenon, as the wind was in the west.

"At about 220° commenced another low ridge of the same character, and extending to about 250°, less elevated than the other, and also less irregular in outline, except that at about 225° a very remarkable protuberance arose from it to an altitude of $1\frac{1}{2}'$ or more. The tint of the low ridge was a rather pale pink; the colour of the more elevated prominence was decidedly deeper, and its brightness much more vivid. In form it resembled a dog's tusk, the convex side being northward, and the concave to the south; the apex was somewhat acute. This prominence, and the low ridge connected with it, were observed and estimated in height towards the end of the totality.

"A small double-pointed prominence was noticed at about 255°, and another low one, with broad base, at about 263°. These were also of the rose-coloured tint, but rather paler than the large one at 225°.

"Almost directly preceding, or at 270°, appeared a bluntly triangular pink body, *suspended*, as it were, in the corona. This was separated from the moon's edge when first seen, and the separation increased as the moon advanced. It had the appearance of a large conical protuberance, whose base was hidden by some intervening *soft and ill-defined substance*, like the upper part of a conical mountain, the lower part of which was obscured by clouds or thick mist. I think the apex of this object must have been at least 1′ in altitude from the moon's limb when first seen, and more than 1′

towards the end of total obscuration. Its colour was pink, and I thought it paler in the middle.

"To the north of this, at about 280° or 285°, appeared the most wonderful phenomenon of the whole. A red protuberance of vivid brightness and very deep tint arose to a height of perhaps $1\frac{1}{2}'$ when first seen, and increased in length to $2'$ or more, as the moon's progress revealed it more completely. In shape it somewhat resembled a *Turkish scimitar*, the northern edge being convex and the southern concave. Towards the apex it bent suddenly to the south, or upwards, as seen in the telescope. Its northern edge was well defined, and of a deeper colour than the rest, especially toward its base. I should call it a *rich carmine.* The southern edge was less distinctly defined, and decidedly paler. It gave me the impression of a somewhat conical protuberance, partly hidden on its southern side by some intervening substance, of a soft and flocculent character. The apex of this protuberance was paler than the base, and of a purplish tinge, and it certainly had a *flickering* motion. Its base was, from first to last, sharply bounded by the edge of the moon. To my great astonishment, this marvellous object continued visible for about five seconds, as nearly as I could judge, after the sun began to reappear, which took place many degrees to the south of the situation it occupied on the moon's circumference. It then rapidly faded away, but it did not vanish instantaneously. From its extraordinary size, curious form, deep colour, and vivid brightness, this protuberance absorbed much of my attention; and I am, therefore, unable to state precisely what changes occurred in the other phenomena toward the end of the total obscuration."

Mr. Dawes adds, that the arc, from about 283° to the north point, was entirely free from prominences or roseate tint.

It would appear from the preceding description, that on the occasion of this eclipse the red flames extended round the circumference of the solar disc, at broken and interrupted intervals, to the extent of 170°, or nearly half the circumference, and that the actual amount of coloured flame occupied about 90°, or one-fourth of the circumference.

Lassell, Airy, and Hind, all observed the same eclipse from different places, and with coinciding results. Hind says that the telescope revealed many rose-coloured flames, and that one on the western limb could be seen without telescopic aid. It was curved at its extremity, and continued in view about four seconds after the sun had disappeared (*i.e.*, after the extinction of "Baily's beads"). The colour of the flames was a full rose red at the borders, gradually fading off towards the centre to a very pale pink. Along the southern limb, for 40° or upwards, there was a constant succession of very minute rose-coloured prominences, which appeared to be in a state of undulation, but without undergoing any material change of form. *An extremely fine line of a violet colour separated these prominences from the dark limb of the moon.* The surface of our satellite during the total eclipse was purplish in the telescope.

Airy says, "The form of the prominences was most remarkable. One reminded me of a boomerang. Its colour, for at least two-thirds of its width, from the convexity to the concavity, was full lake red, the remainder was nearly white. The most brilliant part of it was the swell furthest from the moon's limb." This was distinctly seen with the naked eye. When the sierra or rugged line of projections arose, "it was more brilliant than the other prominences, and its colour was nearly scarlet. . . . The appearance of this *sierra*, nearly in the place where I expected the appearance of the sun, warned me that I ought not now to attempt any other physical observation. In a short time the white sun burst forth, and the corona and every other prominence vanished."

Lassel, in his description, says, "The prominences were of the most brilliant lake colour—a splendid pink, quite defined and hard. They appeared to me to be not quiescent; but the moon passing over them, and therefore exhibiting them in different phase, might convey an idea of motion."

The annular eclipse of 1858 was not very satisfactorily observed, from the prevalence of unfavourable weather. That of 1860 was more fortunate, and of greater importance. Airy mentions that the colour of the red flames was not identical with that which he had seen in 1842 and 1851; but though still full bluish red or nearly lake, was more diluted with white, especially at the roots of the prominences close to the moon's limb. He was again surprised by the appearance of the scarlet sierra, announcing the approaching emergence of the sun's limb.

The eclipse of 1868 created the greatest interest in all countries, and many governments sent men of science abroad to observe it more perfectly.

Why is such a blazing combustion as that of the sun not accompanied with a proportionate manifestation of smoke? This is a question which very naturally arises; yet, possibly, the circumstances will be found to give a very satisfactory answer even to such a difficulty. We have already mentioned the probability which leads us to the conclusion that the solar surface is devoid of water, and that the small proportion of hydrogen gas it possesses floats in the chromosphere or upper atmosphere above the region of white light and intenser conflagration. Now smoke is composed of chemical elements of some weight. It does not float at a very high altitude in our own atmosphere. You can mark this very distinctly by the long horizontal line of smoke which a steam-boat leaves behind it, even in the calmest weather at sea. It is certain, therefore, that the weight of smoke would not allow it to float or rise into a stratum of pure and unmixed hydrogen gas. If it were generated by the solar combustion, it would at its highest altitude very probably never reach further than the base of those conical projections or tongues of flame of which Dawes, Airy, Hind, and others have given us a description, and this may have been the soft and ill-defined substance mentioned by Dawes in one part of his description, and the substance of a soft and flocculent character which he mentions at another; nay, from the atmospheric elevation at which the solar combustion appears to take place, which is compatible only with a conflagration of gases ejected from the solid nucleus, it is quite possible that the rarefaction of the highly heated atmosphere is too great to allow it to retain permanently any smoke, even on the level of the flame bases, and that smoke, where generated, descends first to the bases of the projecting flame, and then down through the photosphere to the level of its own weight, thereby darkening the lower stratum of the solar atmosphere, and rendering it difficult for us to say whether the rents in the photosphere do reveal to us the nucleus of the sun, or merely a dense under stratum of smoke interposed between the nucleus and the photosphere. The photosphere is obviously considerably above the level, according to all astronomical estimates of it as yet before us, of the highest altitude to which it is conceivable the smoke could attain by its own buoyancy merely; and therefore, unless generated higher, we cannot believe that it could be found or appear higher, even temporarily; and that if it did for a time appear at a higher elevation in consequence of its being generated there, it would necessarily sink immediately to its level through all intervening obstructions which were not absolutely impassable. Hence, it might well enough occur that a full proportionate generation of smoke may be a co-operative feature of solar combustion, and yet none of it intervene between us and the clear luminosity of the intensely blazing and fiery photosphere by which it is generated; so completely do new chemical conditions alter the whole aspect of things, and involve totally different consequences: and such an arrangement would be only a proper provision for the unimpeded diffusion of solar light, and in harmony with the other innumerable instances everywhere which exemplify and manifest creative design.

The reader will observe that we have not based these views on the still questioned authority of astronomically applied spectrum analysis, but rather on well-established terrestrial chemical analogy, which the solar spectrum in one particular—that of the composition of the sun's chromosphere—it ought to be noted, very remarkably confirms. From the whole circumstances, also, we can perceive a reason why all the chemical elements we are acquainted with, and which may form portions of the solar chemistry too, with possibly many important and to us altogether unknown additions, may not be found floating in the form even of gas at so high an altitude as the solar chromosphere, and why therefore, even were astronomical spectrum analysis ever so reliable and perfect, we may never be able to discover the existence of such elements in the sun; the reason being that they may never rise high enough in the solar atmosphere to allow the light of the photosphere to shine through them, and thereby reveal their existence to us.

These numerous and important considerations will show how much we have to test and study, and how great an amount of knowledge and light we have yet to receive from that old familiar luminary—the sun.

The questions involved in the more recent pages of the present chapter have been so much dependent for their manifestation, and our first knowledge of them, on the precedent operation of eclipses, that we cannot conclude our subject better or with a more appropriate arrangement of it for the intelligence and breadth of thought which the general reader so much desires, than by supplementing our remarks by all that we consider necessary to say on the subject of solar eclipses.

Eclipses of the sun, then, are of three kinds; viz., *total*, *annular*, and *partial*. To explain the two first of these it is necessary to revert to the simple demonstration of conic sections we gave in a previous chapter, and remind the reader that, of all orbits, the orbits of the planets and satellites are those which are nearest to the form and proportions of a circle or transverse section of the cone. They are not perfect circles, but are very slightly elongated ellipses, as if the cone were cut at a very small angle to the transverse sections. The consequence of this is that the sun is in one of the foci of the ellipse, or rather nearer to one end of the elongated orbit than to the other. And as a result of this fact, the planet describing an orbit round the sun is sometimes nearer to that luminary than at other times. There is a perihelion or nearest point of the orbit to the sun therefore, and an aphelion or furthest distant point of the orbit. The earth's orbit being in this respect of the same elliptical form as other planetary orbits, it follows that at certain points of its annual motion round the sun it is at the nearest point of its orbit to its luminary; at other points of six months' period, or the semi-circumference of the earth's orbit from its nearest point, it is at its aphelion point, or the point furthest away. The difference between the least and greatest distance of the earth from the sun is as 0·9,832,249 to 1·0,167,751, the mean distance of the earth being taken as one. Assuming roughly that this difference exhibits 3,000,000 miles, it will follow that the sun's apparent magnitude is increased or diminished by the effect of that difference of distance between us and him at the perihelion and aphelion points of our passage round him in the course of the earth's orbitual motion. This effect of perspective, which diminishes optically the appreciable diameter of his disc, is further liable in the case of an eclipse to be affected by the position of the moon for the time being in its orbit. When the moon is at the nearest point of its orbit to the earth, its apparent magnitude is increased; and when it is at its furthest point, its apparent magnitude is proportionately diminished. It so happens that though the sun is so much further away from us than the moon, the discs of both have very nearly the same apparent breadth and magnitude, the disc of the sun being sometimes larger than that of the moon, and the disc of the moon sometimes larger than that of the sun. The consequence is, that when the moon is at the nearest point of its orbit to the earth, and the earth concurrently at the furthest point of its orbit from the sun, the moon's disc will cover more of the heavens than the sun's disc will do; and if at such a time the moon's path should lie concentrically across the apparent path of the sun, the moon's disc will cover a space larger than the sun's disc, and the sun will be totally eclipsed by the intervention of the moon between him and us. If, on the other hand, an eclipse should take place concentrically between the sun and moon, by the disc of the latter interposing between us and the sun at a period when the earth is at the nearest point of its orbit to the sun, and the moon is concurrently at the furthest point of its orbit from the earth, then an annular eclipse of the sun will be the result; that is, an eclipse in which the disc of the moon measured against the disc of the sun will appear smaller than the sun, and a ring of light will in consequence appear all round the moon from the edges of the sun's imperfectly covered disc. This will be better understood by the plate, which reduces the annular and total eclipses to demonstration.

Partial eclipses of the sun arise not so much from the position of the earth or the moon in their respective orbits as from the fact that in such cases the centre of the moon does not pass across the centre of the sun, and therefore the sun while eclipsed exhibits at the maximum of the eclipse a crescent form merely, or a projection more or less of the moon's disc over the solar disc. This effect will be easily understood also from the plate.

The phenomena connected with red flames, which we have just been considering, are only exhibited during and in connection with total eclipses; as, if there be any important amount of the sun's edge, or limb, as it is called, visible, all subordinate lights or colour connected with his disc disappear before the superior brilliancy of his white light when thus partially manifested; and hence arises the fact that no attempt is made by astronomers to observe the chromosphere during mere partial eclipses.

One of the fine phenomena connected with total eclipses is the appearance called "Baily's beads," so called after Francis Baily, who was the first to describe them, in a memoir published by him in 1836. This appearance is a result of the combined edges of the sun and moon immediately before and immediately after the period of complete obscuration, the edge of the solar disc on the side over which the moon has yet to pass being reduced to an extremely thin crescent line of light, so that the projecting portions of the moon's edge—its mountain peaks, in fact—which give to the edge of the lunar disc a serrated appearance, cut the crescent light, leaving it only a series of points of light visible to us between peak and peak, or through the hollow valleys of the moon intervening between mountain and mountain. This effect first takes place just before the moment of total obscuration on the edge of the sun yet to be passed over and obscured by the interposition of the moon, and then after total obscuration it reappears on the opposite side of the solar disc as the sun emerges from the total eclipse—both edges of the moon, and indeed the outline of the lunar disc generally, being serrated by mountain peaks and projections. Mr. Hind, in the account he has given us of the eclipse of 1851, observed by him at Rævelsberg, near Engelholm, in Sweden, gives a vivid account of this beautiful phenomenon. He says, "In this case they were clearly to be attributed to the existence of many mountains and valleys along the moon's edge, the sun's light shining through the valleys and between the mountain ridges so as to produce the appearance of luminous drops or beads, which continued visible some seconds."

VULCAN.

CHAPTER XV.

The discovery of Vulcan—M. Le Verrier's calculation and predication of Vulcan's existence—Encke's preliminary facilitation of the discovery—Lescarbault's observation—Observation by Mr. Lummis—Le Verrier, Radau's and Valz's calculations of Vulcan's elements—Other observations of Vulcan, and confirmations of the discovery—Permanent difficulties attending the observation of this Planet.

One of the most remarkable additions which recent discovery has added to the solar system is that of the planet Vulcan, the planet nearest of all to the sun, and interposed between the great luminary and the orbit of Mercury. The means by which this discovery was made are altogether of an extraordinary character.

M. Le Verrier, the distinguished French astronomer, whose name stands conjoined with that of Mr. Adams, of Cambridge, in the honour of having made those calculations of the perturbations of Uranus which led to the predication of the new planet Neptune, and to which subject we will endeavour to do impartial justice in the proper place, was engaged in an investigation of the theory of the orbit of Mercury, the estimate of whose mass had recently undergone corrections from the cometary observations of Professor Encke, which have been noticed in our treatment of comets. The corrections effected by Encke on Laplace's excessive estimate of Mercury's volume no doubt greatly conduced to the accuracy with which M. Le Verrier's investigations were pursued. Having completed his examination of this subject, Le Verrier arrived at the conclusion that an error in the perihelion motion of Mercury could only be explained by the assumption that the mass of Venus had hitherto been underestimated to the extent of a tenth part or more; or that, as the only conceivable alternative, some yet unknown and unseen planet existed between the orbit of Mercury and the sun. These two alternatives were laid before the scientific public by Le Verrier, without any commentary on his own part to indicate a preference for either: he did not positively, but only alternatively, predicate the existence of Vulcan.

On the hypotheses, however, becoming known a till then obscure French physician residing at Orjéres, Eure-et-Loire, named Lescarbault, announced that he had, on 26th March, 1859, observed the passage of an object across the sun's disc, which he thought might be a new planet, but that he did not venture to proclaim his discovery until he had observed again and confirmed his impression. Having given an account of his observations, Le Verrier resolved to visit him. At the interview Le Verrier at first maintained a strict incognito, and after putting both Lescarbault and his astronomical knowledge, as well as his amateur and far from perfect observatory, to the most crucial examination, was compelled to come to the conclusion that the physician was right, and that the very defects of his instruments, and the errors they had led to in his calculations, elicited the evidence of Lescarbault's great personal care and skill, and his entire competency for the treatment of such a subject, which, with a better set of astronomical appliances at his command, might have been a very complete triumph.

From Lescarbault's observations Le Verrier calculated that Vulcan's mean distance from the sun is 13,082,000 miles, and that its revolution in its orbit is completed in a period of nineteen days seventeen hours. Its mean distance is thus somewhat more than a third of the mean distance of the next planet, Mercury, from the sun. A body describing so small an orbit, and traversing it so frequently—about eighteen times every year—might be expected to make frequent observable transits across the solar disc, and thereby afford many opportunities of observing it. It was expected to make a transit in March or April, 1860, but was not observed, though watched for several days, and it was not till 20th March, 1862, that anything was found by further observation confirmatory of its existence. On that date Mr. Lummis, of Manchester, while examining the solar disc, observed, between eight and nine in the morning, a spot with a rapid proper motion passing across it, and both he and a friend whose attention he directed to it were impressed with its clearly defined circular form. This was no passing glance about which there could be a possibility of mistake, for he observed it for twenty minutes, though he was unfortunately prevented by other duties from perfecting the observations which the opportunity might have afforded. He, however, noticed that its apparent diameter was about 7″, and that it passed over about 12′ of arc in the time he had devoted to it. On communicating with Mr. Hind, the latter decided that 6′ was a nearer value of the distance which had been traversed, and that 12′ was excessive.

Calculations made by Radau and Valz from Mr. Lummis' observations give the slightly conflicting result of Vulcan's orbit and period as follows:—

Radau - Mean distance, 13,174,000 miles; period, 19d. 22h.
Valz - „ 12,076,000 „ „ 17d. 13h.

It will be apparent from these results that there is a very close accord on the part of Radau with the *mean distance* calculated by Le Verrier from the observations of Lescarbault, and a similar accord with the *period* calculated by Le Verrier from the same observations. It was also deduced from the position of the nodes that transits would be confined to the periods of our year, between 25th March and 10th

April and between 27th September and 14th October. It is quite possible that all these transits occur regularly enough, and yet that they have escaped the amount of observation we have expended on the watching of them, from the simple fact that the observation has never yet in any instance been continuous throughout the whole of any one possible period. This will be easily understood when the reader bears in mind that no single watcher can observe continually throughout more than half of the period, from the circumstance that at those times of the year, spring and autumn, about one half of the period of transit occurs during the night.

Many other observations of round spots passing across the solar disc, however, had been recorded before Le Verrier's statement of his alternatives from the perturbations of Mercury justified the suspicion that we had another interior planet to discover. Schmidt on two occasions, at an interval of twelve years, saw a black or dark body pass rapidly across the disc of the sun; Stark and Fritsch, respectively, observed similar appearances on two other occasions. These all occurred, curiously enough, in October, and within the autumnal period of Vulcan's possible transits, and they occurred in the years 1849, 1847, 1819, and 1802; and possibly enough some of those appearances which Arago has ascribed to dense and opaque comets, as referred to in our chapter on these bodies, may be more justly due to transits of Vulcan. No contradiction of the observations of Mr. Lummis has been attempted, and it does not appear possible that he and his friend could have been mistaken for a period of twenty minutes; we are, therefore, the more inclined to disregard the contradiction which has been given to the observations of M. Lescarbault by M. Liais, an observer in Brazil, who denies that the appearance reported by Lescarbault occurred, on the ground that he was observing the solar disc at the same time, and saw nothing of the kind. It is quite possible that a slight error in identifying the time may account for the good faith of both parties, for it is manifest from the manner in which Lescarbault was taken by surprise by Le Verrier, and the satisfactory manner in which he endured his severe and rigorous cross-examination, that any suspicion of his perfect integrity is out of the question. It is also apparent that all circumstances conspire to confirm his accuracy, the pertubation of Mercury, the observations of Lummis and others; and also a corroboration derived from the third law of Kepler. It is only to be regretted that no attention has been paid to the other alternative presented by Le Verrier as to the mass of the planet Venus, to make sure that an explanation of the perturbations in the perihelion motion of Mercury is not entirely excluded in that direction. Such an investigation, though we do not consider it would at all invalidate the positive evidence as to the existence of Vulcan, which we must now regard on adequate evidence as the first planet of the solar system, might lead to the discovery of minor facts on which the estimate of the mass and other elements of Vulcan in some degree depend; for there can be no question that without Encke's correction on Laplace's estimate of Mercury's mass, this calculation would have been very much complicated, and we should have had to assume, in considering Le Verrier's alternatives, that the mass of the disturbing cause, whether it were Venus or Vulcan, must have been much greater than we now require to do.

It will be seen from the preceding facts, in regard to Vulcan, that all we know of this, we might almost call it *inchoate*, planet is very little up to the present time. Its existence is, however, established by two totally independent modes of proof; namely, those of observation and antecedently announced necessity. We do not say that this is the very best and most reliable way in which such a truth can or ought to be established, for where the necessity is announced before the *satisfactory discovery*, the wish is apt to be the father to the thought. Yet such was the way in which the discovery of Neptune was made, as will be seen when we come to consider that planet; and astronomical science can therefore refer to an unchallengeable parallel on the subject. Doubtless, further confirmation will be forthcoming as more extended observation is applied; but when all is done, there is much which it is to be feared we shall never know of this peculiarly situated body. Whether it have an atmosphere, whether a rotation on its axis, whether it be flattened at the poles, whether it be attended by any satellite, and what is its chemical composition, are all particulars which it may possibly never be in our power to ascertain; for the difficulty at present is to get a view of it all, for the very shortest period, and under circumstances in which spectrum analysis is plainly impossible, and very minute observation precluded by the dominant influence of solar radiance, which conceals it absolutely at all times, save during the brief period of a transit across the solar disc.

MERCURY AND VENUS.

CHAPTER XVI.

Mercury and Venus—Characteristics common to both—Their phases—Elements of Mercury—Its Atmosphere—A possible peculiarity of Mercury's Atmosphere explanatory of Schröter's observations—Mercury's Zones—Climate, etc.—Venus—Her elements—Her Atmosphere—Peculiarity of the Atmosphere of Venus—Venus as Vesper and Hesperus—The Satellite of Venus.

The planets Mercury and Venus in many respects resemble each other, more especially in the exhibition of *phases,* or those changes from crescent to full and from full to crescent which result from their being nearer to the sun than the earth, and there is nothing so essentially different in the character of either as to require that they should be treated in separate chapters. The manifestation of phases in these planets differs in their cause from those of the moon only in the fact that they revolve round the sun, while the moon revolves round the earth, so that the fully illuminated disc of the moon, or "full moon," is seen only when the moon is on the further side of the earth from the sun, while the fully illuminated discs of Mercury and Venus are seen when these planets are on the opposite side of the sun from the earth. This will be better understood by the diagram, in which it will be apparent that to an observer from the earth the phases of Mercury, Venus, and the moon can only occur when these bodies are in the positions indicated.

The mean distance of Mercury from the sun is	35,392,638 miles
The extreme distance	42,665,560 „
The least distance	28,119,716 „
Its orbitual motion is at the rate per hour of	105,330 „
and its orbit is traversed in about 88 days, which is the length of its year.	
Its diameter is estimated at about	2,962 „
a little more than one-third that of the earth.	

Its polar diameter has been stated at one-twenty-ninth less than its equatorial diameter.

Its rotation on its axis is completed in 24 hours, 5 minutes, 28 seconds, according to Schröter, and its day is therefore somewhat longer than ours.

The inclination of its axis to the ecliptic is considered to be about 63°.

It had been alleged that Mercury had an atmosphere; but Sir William Herschel has positively denied this, and stated that no atmosphere can be detected. There is great difficulty in getting a satisfactory view of this planet, in consequence of its nearness to and close attendance on the sun, with whom it regularly descends at sunset below the horizon wave in spring and autumn. In spring it remains nearly two hours above the horizon after sunset, and in autumn it appears above the horizon nearly two hours before sunrise. These are the periods at which it is at the greatest easterly and westerly elongations of its orbit from the sun. It can, however, be frequently seen in the daytime by the aid of a good telescope; under all the disadvantages, however, of the brilliancy of the adjacent sun. It has not been observed to be attended by any satellite.

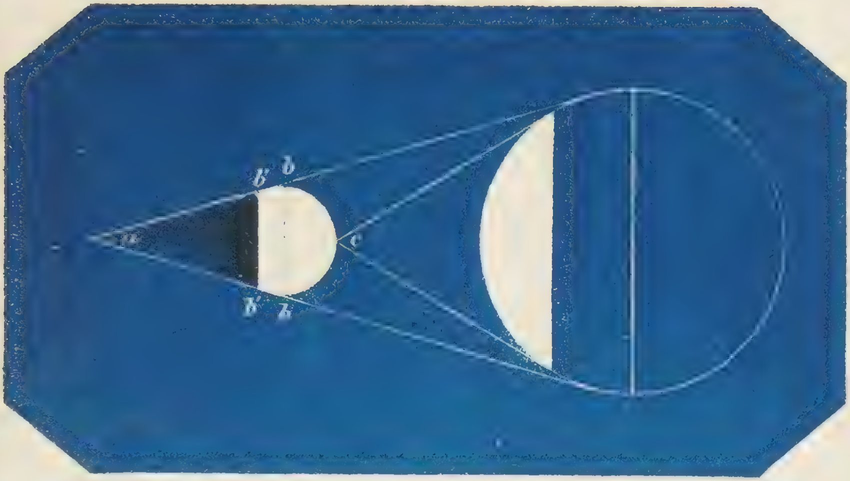
It is stated that a peculiarity of the phases of Mercury is that they are not always so broad as they should be, a circumstance which has not been satisfactorily accounted for. It never recedes from the sun more than thirty degrees. The inclination of Mercury's orbit, combined with the smallness of the orbit itself, produces the effect that every time it completes a revolution in its orbit it makes a transit of the sun—passing right between us and the solar disc when at the nearest side of its orbit to us; and, at the point of its orbit furthest from us, is eclipsed by passing behind the sun; so that it makes a transit, and suffers an eclipse, every revolution, or at an interval between the events of nearly forty-four days. In consequence of this the smallest crescent of Mercury is never visible to us, nor is his fully illuminated disc ever seen by us. At full he is behind the sun, and when entering on his transit behind, or eclipse, he is gibbous, or only near the full—the deficiency in the roundness of his disc being on the side furthest from the sun. On emerging from behind the sun the gibbosity is on the opposite side of Mercury's disc, and again, on the side furthest from the sun. From this point the diminution proceeds till his phase is reduced to his smallest visible crescent, and then the disc becomes wholly dark during his transit, after passing which the crescent reappears on the opposite side of the disc.

The question whether Mercury has an atmosphere is still one of considerable doubt; for, although the impression of Schröter, occasioned by the appearance of the planet's transit in 1799, who then saw a vaporous envelope like a nebulous ring all round it, instead of a perfectly sharp and clearly defined dark disc, was contradicted by Sir William Herschel, as already mentioned, a subsequent observation by Beer and Mädler, in 1832, enabled them to conclude that Mercury had a perceptible atmosphere. Other observers, however, still resist this conclusion, because they have not, on their part, been able to confirm the observations on which it is based, save that the breadth of the illuminated portion is not so great as it should be, nor the edge or terminator of the illumination so well defined as might be expected. There is one circumstance, however, which should be kept in view in any consideration of this question, that Mercury's close proximity to the sun must render the rarifying influence of solar heat upon the atmosphere of the planet, if any, very great, so that in ordinary circumstances the atmospheric element would be too transparent to be visible or sensible to observation. But let us suppose that Mercury has an ocean, and that ocean occupies an extensive surface of one side of the planet, and a very small portion of the other surface or hemisphere, a curious result might be easily and reasonably enough supposed to follow from such a circumstance, which might render the observations of Schröter quite as correct as those of others who have been unable to confirm his conclusions; for it is hardly possible to conceive that he could be mistaken in what he says he *saw* during the transit of 1799: for if the transit occurred at the time when the ocean was on the side of the planet exposed to the solar heat, we can quite understand that the temperature might keep the atmosphere in a state of perfect transparency; but if, on the other hand, the transit took place at a time when the ocean was on the dark and colder side of the planet, it is just as conceivable that evaporation might fill the atmosphere with mist, and thereby render it visible during such a transit, when it is invisible during every other. It would be a curious circumstance if some further observations of unquestioned accuracy should confirm Schröter during one exceptional transit, and thus lead us to the inference that Mercury has not only an atmosphere, but a partially and hemispherically distributed ocean and land surface. The very possibility of such being the case shows us the importance of never rejecting the testimony of an *honest* eye-witness, and not a breath of suspicion has ever been emitted against Schröter's integrity.

Another peculiarity of Mercury is, that from its proximity to the sun the solar light and heat must extend over a considerable extent of its surface more than a hemisphere, so that were any observer situated just within the umbra or shadow of Mercury, he would in all likelihood be able by the aid of refraction to perceive a ring of luminosity all round the edge of the planet, even though his position concealed the whole disc of the sun from his view—this will be understood from the plate; and, indeed, the disc of the moon must appear less than it really is during an annular eclipse, from the same circumstance.

The eye of the supposed observer is placed in the umbra at *a*. The extent to which the solar light falls beyond the exact hemispherical diameter of the planet is shown at the lines *b′ b′*, which are beyond the line of the true diameter *b b*. The diagram is not drawn exactly to measure, but merely for explanation. Were the moon taken as represented by the sphere *c* in the diagram, instead of Mercury, then the eye of an observer on the earth during on annular eclipse would be beyond the umbra, say at *d*, and the same effect on the dark hemisphere of the moon would take place as a reduction of its apparent diameter, though to a different extent. This fact will render it evident that the zones of Mercury have a wider range than the zones of the earth, in proportion to the respective surfaces of the two planets; and, combined with the great inclination of Mercury's axis to the plane of its orbit, it follows that Mercury has no temperate zones, or perhaps we should more correctly say no frigid zones, but only a torrid zone and then a temperate zone extending to his poles—equivalent to what would be the condition of the earth it the torrid zone extended 45° to the north and south of the equator, and the frigid zones extended, to meet this,

MERCURY and VENUS



[illegible] From the cause mentioned in the text [illegible] Mercury [illegible] the [illegible] invisible to him [illegible] the solar [illegible] reduced [illegible] Planet

Mercury crescent,

Venus
with [illegible]

Showing the irregularities of the terminator [illegible]

45° south from the north and 45° north from the south pole of the world.

From its nearness, the sun is a much larger object to an observer on the surface of Mercury than to an observer on the surface of the earth. The sun's diameter would embrace fully more than two and a half degrees of a circle of which Mercury's mean distance is the radius, while on a circle of which the earth's mean distance is the radius the sun's diameter is reduced to an arc of 32′ 3″, so that the apparent diameter of the sun at the distance of Mercury would be five times as great as at the remoter distance of the earth. This makes the sun's disc twenty-five times as large to Mercury as it is to us, and the sun in the vertex of observers on Mercury would, from side to side of his disc, shine perpendicularly down upon a circular area of Mercury's surface of more than 150 of Mercury's geographical miles in diameter, while now to us he is vertical from side to side of his disc only over an area of one twenty-fifth part of that extent, or about $32\frac{1}{3}$ of one of our geographical miles in diameter. The climate and seasons of Mercury must be very variable and unequal, both from the inclination of his axis and the elongation or ellipticity of his orbit. The interior edge of his crescent and other phases show considerable ruggedness and inequality of outline, suggestive of the probability of his surface being pretty boldly broken up by mountain ranges and valleys. Schröter observed dark bands on the disc of Mercury, from which, taking them to indicate an equatorial zone, he deduced the inclination of the polar axis, and it was by the peculiarity of the inequalities along the inner edge or termination of his phases, and the periodicity of some of them which were found to be capable of identification, and more especially a truncated peculiarity of the south horn of his crescent, which regularly appears at one stage of his revolution, that the period of his rotation on his axis was inferred.

Though Mercury is so much smaller than the earth, his density is much greater, as his weight or attractive power is about four-fifths, and his density therefore about one and a half times that of the earth.

We will now proceed to notice the third planet of our system, Venus, the second of the old planets, whose mean distance is nearly double that of Mercury from the sun, viz. . . . . 66,131,478 miles

Extreme distance . . . 66,585,947 „
Least distance . . . . 65,677,009 „
Its orbitual motion per hour is . 77,050 „

Its orbit is traversed in 224 days, 16 hours, 49 minutes, 8 seconds; while its rotation on its axis is completed in 23 hours, 21 minutes, 23 seconds.

Its diameter is estimated at 7,510 miles, being very nearly that of the earth, and the difference between its polar and equatorial diameter is very little.

The inclination of its axis to the ecliptic is 73° 32′.

Venus is now, by very general consent, admitted to have an atmosphere of considerable density, and also to have mountainous elevations, detected by the irregularities in the interior concave edge or terminator of the crescent, and a truncated appearance at the southern end, in which particulars it is similar to Mercury in appearance. As already stated, Venus passes through all the phases from crescent to full, which are manifested by Mercury and the moon. It is also found that the interior ridge of the phase on the disc of the planet is dim and not sharply defined, and that the phase is different in real from calculated breadth, an effect which may be ascribed in this instance, with some degree of certainty, to its atmosphere. Spots also exist on the surface of Venus, and the existence of frozen polar regions, covered with snow, has been intimated.

It is quite possible, on account of the higher temperature of Venus, as compared with that of the earth, that the apparent density of its atmosphere is occasioned by permanent vapour or mist diffused through it, which would also account for the fact that an appearance of phosphorescence is ascribed by Webb and others to the dark side of the planet beyond the edge of the crescent, and which renders the entire disc of Venus visible under the same circumstances in which we see the dark disc of the moon, or what is popularly called "the old moon in the new moon's arms." In the case of the moon this appearance cannot be ascribed to atmosphere, but is known to be the reflection of earthshine, as it is called, or that degree of luminosity which the reflected light of the sun on the surface of the earth enables the latter to throw on what may be considered as the moon's night. But then there can be no such thing as earthshine, or any other kind of reflected luminosity on the night side or dark disc of Venus; for it is a vexed question whether Venus be attended by any satellite, and certainly its companion, if it have any of that character, is too insignificant to give on the disc of Venus a moonlight intense enough to be seen at the earth, since it is unable to give any very strong luminous appearance of itself capable of general detection by our astronomy. But were Venus invested, as we have supposed, with a vaporous atmosphere, it is quite conceivable that the interweaving of solar radiation through it might account for the whole extent of the darkened disc being seen, and manifesting something of a phosphorescent appearance, or "ashy light," which the dark part is found to have in the neighbourhood of its inferior conjunction.

Venus is never seen further distant from the sun than about 47°. This, however, is about 18° further than the greatest elongation of Mercury's orbit, and enables Venus to be seen with much greater ease than Mercury, and at times when the latter is below the horizon. In one part of its orbit it precedes the sun by about that distance (47°) in his eastern place in the heavens, and rises purely and beautifully before him, heralding the dim dawn and vestibule of the morning, from which circumstance it received from the ancients the poetical name of Vesper, or the Morning Star. When at the other and opposite side of its orbit, it follows the setting of the sun by about the same distance in his western course, and shines forth like a solitary diamond on the paling brow of even—the first seen of all the crowding stars. In this position it received the name of Hesperus, or the Evening Star—"the dewy star of even." But though thus well seen and conspicuous in all ages to observation by the naked eye, Venus places peculiar difficulties in the way of astronomical curiosity, and, like a shy queen of beauty, conceals much of her charms and interesting features in the dazzling brilliancy of her veiling garment of light, which is so intense as to make her quite clear and conspicuous at certain times during the day, as may have been observed by many of our readers in the early part of 1862. This circumstance makes day the best time for telescopic observations on this beautiful planet; though, even then, and while under the superior influence of associated sunlight, its lustre is embarrassing, on account of its intensity. This is, however, greatly compensated by the aid which the planet gives to navigation; as from the very same cause, its brilliancy, it is frequently seen at night—when observations of the sun cannot be taken on account of bad weather during the day—and, its position with reference to the sun at all times of the year being known by the nautical tables, the sun's position can thence be deduced with perfect accuracy.

A great difficulty has attended the question whether Venus be accompanied by any satellite, and the balance of evidence appears to be in favour of the conclusion that it has such a companion; for the assertion of its existence does not rest on any single or unsupported testimony, but upon the combined evidence of many independent observers from totally different points of observation, and at an interval of almost a century between their observations. Cassini proclaimed that he saw a small crescent star on the western side of Venus in 1672, and about the breadth of Venus herself distant from her southern horn. He saw it again in 1686 on the east side of the planet, and watched it for half an hour, after which the dawn rendered it invisible. Short, in 1740, also saw it. It was seen twice in 1764 by Rödkier, and twice during the same month by Horrebow—both at Copenhagen. It was also seen by Scheuten and Montaigne (by the latter four times) in 1761; and, perhaps, never in the history of the science has so much positive evidence been treated with distrust, simply because others have not been able to detect what it is alleged they should have seen, as well as those who allege they did see it. It is certainly perplexing; and yet some peculiarity in the satellite's orbit and motion may yet help to account for it, together with the fact that it may, in many positions of the planet, be completely concealed by solar radiance; for in any instance in which the satellite happened to be at a point of its orbit between Venus and the sun, it is quite possible it might escape observation from the combined and dominant brilliancy both of the sun and the planet, and the question may long remain unsettled,—when it is to be caught in the best position. The dates of the alleged observation of it hitherto are, chronologically, 25th January, 1672; 28th August, 1686; 23rd October, 1740; 3rd to 11th May, 1761; and 3rd, 4th, 10th and 11th March, 1764; and they are worthy of being noted for consideration. The periods of the year, therefore, were January, March, May, August, and October, and the intervals in years 3, 14, 21, 68, and three and a half years, allowing for difference of position in the orbit of the satellite, appear to be a pretty approximate common measure of all the intervals; but of course there are many other questions of too intricate a nature for detail in this work, which may seriously affect this inquiry.

Some attempts have been made to calculate an orbit from the obervations, but they do not appear to be satisfactory, nor quite in accordance with other facts.

THE EARTH.

CHAPTER XVII.

The Earth—Phraseology applied to appearances—The Earth's Elements —The Earth the centre of the Universe to our view—The Pole Star—Successive Pole Stars—γ Draconis, the Pole Star of the Ancients—Future Pole Stars, Vega, and others—Southern Sideral Hemisphere destined to become visible from Northern Terrestrial Hemisphere—Changes in the Axis Major of the Earth's Orbit, or line of the Apsides — Changes in the heliocentric positions of Venus and the Earth discovered by Le Verrier—Creation in reference to this World?—Inhabitants or habitability of other Planets?

Our readers who have patiently accompanied us so far have had a wide circuit placed before them, with a dim imaginary peep through the nebulæ of remoter astronomical space at the still wider and interminable infinitude beyond—the boundless and incomprehensible. It is with something like a sense of resting on our way that we come down and back in the present chapter from these immensities, by way of the sun and inferior planets, to that sublunary sphere, the earth—the home of our humanity. That world we know so well as the scene of so many chequered histories—of such aspirations, and fears, and joys, and sorrows—the region of toiling day and peaceful night—of cradles and graves ever filled and filling—of vain ambitions and wasted opportunities—of dark crimes—of multitudinous mercies scattered broadcast amid the miseries, the waywardness, and the wickedness of life.

After what we have been contemplating in other regions of space, how strange it seems to us to come down to this small orb, and from a petty region of its surface long known as the Roman world, imagine ourselves in the centre of the universe, with the sun, moon, and stars all moving and completing their orbits round us at the rate of twenty-four hours each, and all humble handmaids and attendants on that irrepressible Ego—mother earth!

Well, appearances, at least, were in favour of ancient ignorance, and we doubt whether we shall ever be able to make human language so scientifically precise as to drop saying "the sun is rising," and "the moon is going down," and substitute, as a matter of learned accuracy, such phrases as "the horizon is sinking toward the east, and revealing the sun," or "the horizon is rising from the west, and concealing the moon." These expressions are, we fear, too circumlocuitous for popular use—a little too ponderous, both in form and phrase, for even pedantry to propound them. Our *savans* have apparently no short Greek or dog Latin way out of the difficulty; and that hierarchical body, the Quakers, does not appear to have any aptitude for science; so that there seems little likelihood of our getting our popular phraseology rectified to scientific integrity. We wonder whether any broad-brimmed Obadiah, disdainful of right honourables or false courtesies, ever perpetrated the indiscretion of an evening, when doffing his veracious drab, of ordering the attendant to call him at *sun-rise*, and, remembering his *lapsus* in the morning, virtuously winked hard and slept on, rather than be wakened on the instruction of a phraseological lie—and thereby self-denyingly lost a train and a day's profit. But perhaps the rev. brotherhood hold faith with the contemporaries of Galileo, or believe the stability of the earth to be guaranteed by that of the Bank of England. Of course, an article of faith is everything as matter of conscience.

But, in the eloquent language of Alessandro Gavazzi, in one of his finest perorations, "the earth will continue to go round with the octogenarian Galileo, though it roll in its diurnal motion the lumber of the conclave as well as the brains of the astronomer!" At least, we expect so for some time yet. Let us hope that ere this the eminent Father Secchi has succeeded in convincing and converting the conclave.

The mean distance of the earth from the sun, as ascertained by recent correction, is not 95 millions of miles, but, more nearly . . . . 91,430,220 miles.
Its extreme distance is . . 92,965,489 ,,
Its least distance . . . 89,894,951 ,,

Its orbital motion is at the rate per hour of 65,533 miles, and its orbit is traversed in 365d. 6h. 9m. 10·7s.

		Bessel.	Airy.
Its diameter is	(equatorial)	7925·604 mls.	7925·648 mls.
,,	(polar)	7899·114 ,,	7899·170 ,,

Its rotation on its axis is completed in 23h. 56m. 4s., or three minutes and fifty-six seconds less than twenty-four hours.

The inclination of its axis to the plane of the ecliptic is 66° 32′.

The ecliptic is the great circle in which the sun *appears* to move round the earth annually, and on or over which the sun *is* vertical in the course of an entire annual revolution of the earth in its orbit round the sun.

Although it is not true that the sun and stars move round the earth, yet astronomers are compelled for convenience to assume their apparent motion to a very considerable extent for the mapping, sub-divisions and general convenience of science, as if the earth were really the centre of the universe; for the simple reason that the earth's surface is the *point of view* of all human astronomy. Hence the extension of the plane of the earth's equator outward into infinite space is adopted as the division between the northern and southern celestial or sideral hemispheres. The prolongation of the polar axis into infinite space is held to fix the position of the celestial poles or the central parts of the northern and southern sideral hemispheres, and the zodiacal constellations are subdivided into twelve to accord with our months, and into four groups, of three constellations each, to accord with our terrestrial seasons. The obliquity of the ecliptic, the plane of the equator, and the polar axis of the earth, however, are not absolutely fixed and unchangeable lines or points; and the sideral hemispheres depending on them for their division and polar centres are also, and as a consequence, not fixed either. The present pole star, *Polaris*, which we have so frequently mentioned elsewhere, was not always the pole star, or nearest permanent star to the northern prolongation of our polar axis through sideral space, and it will not always continue to be so. The pole star, by which the Phœnicians navigated the seas of antiquity, was a star called *gamma* Draconis, which our readers will find marked with that letter γ in the constellation of the Dragon at the top of the Dragon's tail, and about twenty degrees to the south of the present pole star. This was "the cynosure star of the mariner," when Carthage was founded, and Troy, old Illium, was besieged and fell. Solomon, doubtless, beheld it as such when he was engaged in building the temple, and may have set his plumb and line by it when he made that molten sea, supported on rows of cast oxen—"three looking toward the north, and three looking toward the west, and three looking toward the south, and three looking toward the east." And wistfully often must Ulysses have watched its midnight steadfastness on his adventurous journey home, after all the triumph Homer sang was over. And it seems to be absolutely certain that the Pharaohs built their great pyramids with special reference to its position. The entrance passages of the pyramids still look "toward the north;" and so would Solomon's three oxen have continued to do, had the Babylonian spared them, or had their successors in the temple restored "survived," to make another bull, the siege of Titus and the conflagration which smote utter consternation and despair to the heart of the desolated and thenceforth exiled Israel. But Solomon and the Pharaohs would now vainly look for their old polaris in its place, and Ulysses, we fear, were he to trust his ancient cynosure, would grievously miss the way to home or arrive too late for the faithful Penelope to evade the pertinacity of her suitors, from which Homer has so ingeniously made up the interest of the Odyssey. If Cheops, the founder of the great paramid, really intended to sleep till his Polar acquaintance γ Draconis looked in at the old passage again, after a circuit of the heavens, to awaken him, we have at length an intelligible explanation why he made his intended bedroom so strong; for nothing but sheer dead inertia has saved it as well as himself from Belzoni and the British Museum; and even if time should spare it, the greatest nation in all creation will have it away in chippings long before γ Draconis becomes Polaris again. The pole has to claim acquaintance with and point to many a brilliant star ere then, making each a polaris on its way; and possibly, if any of us live long enough (!) we may, amid cockney mummies, be able in the neighbourhood of St. Paul's to verify and correct Sir John Herschel's Cape observations, and make acquaintance with the astronomy of the antipodes. In about twelve thousand years the Southern Cross will be as easily seen from the Greenwich observatory (*cæteris paribus*) as Sirius now is in our London winter, and the brilliant Vega will be near enough the northern polar axis to claim the honours of the cynosure.

The axis major of the earth's orbit, or its longest diameter, otherwise called the line of the apsides, changes every year under a direct annual motion to the extent of about one-sixtieth of a degree, which causes the seasons to vary in length from time to time; and the eccentricity of its orbit diminishes for long periods extending to some hundreds of years—having a tendency to become a perfect circle, and lose its ellipticity, but for the fact that, after proceeding for a period not yet well defined, it begins to increase again. The peculiarity of the change in the direction of the axis major of the earth's orbit, and the contraction of its ellipticity and re-expansion of it again, may be a feature of all orbitual motion, for anything that is yet known, and may lead to the discovery of some new law affecting the combined operations of tangential or centrifugal force and concentric attraction. At present the cause is not known.

Le Verrier has discovered an inequality, which in about 240 years passes through all its stages, affecting the heliocentric positions of Venus and the earth, and which at its greatest point alters the position of the earth to the extent of about 2″ viewed from the sun, and the position of Venus to the extent of 3″.

Is it possible to conceive, amid all these multitudinous and immense truths—these innumerable and interminable connections and arrangements of material creation, that the vast region astronomy is privileged to explore, can have been created and arranged with reference to this little world of ours only, and at the same date; and that it is bound up in the same destiny, and doomed at length in spite of all its magnitude to pass away like a scroll, and its elements to melt with fervent heat? We are aware that in these times there are officiously good men who will spend painfully ingenious lives to dilute Scripture expression in accordance with popular objections on this point, because science in reply to the question has had the audacity boldly to answer No! But what is the intrinsic value of this scientific negative on the evidence of science itself? The orbs which fill the interminable chambers of space are all connected by balancing and adjusting attractions and motions, so far as astronomy has been able to explore. To this there is not a single exception throughout all that can possibly be habitable of matter; for where in any direction has the astronomer failed to establish it, but only where his powers of investigation have failed?—Where it has been beyond his reach to explore further, and where, if he has not found confirmation, he has been equally unable to find contradiction. There is, we repeat emphatically, not a solitary exception within the whole range of astronomical knowledge. Sir William Herschel, and others since his time with higher powers of observation, have vainly examined nebulous matter with the view of ascertaining the development of new creations, or the dawning arrangements of new spheres and systems. There is no such thing. All is already, everywhere, fully developed and complete. There is nothing to show that all the orbs and systems astronomy knows of were not simultaneously created and simultaneously balanced and distributed through space, and prescribed their several bounds. It is as difficult to conceive that they were created at different times, so far as we *know* of their connection with each other, as that the beam of a balance can be equipoised while a portion of the length or ponderosity is wanting from the one end or the other of the beam. The whole evidence of this great science, so far as it gives positive evidence on the subject at all, is in favour and corroborative of the idea of simultaneous creation. And what more natural than that things knit together so, and mutually dependent, should endure and perish together also; or give way at one part only when rearrangement of the whole is resolved on? These arguments against the mutual dependence of creation, and for the insignificance of one part, and the preponderating importance in favour of another, do not begin clearly and coherently anywhere. What, for example, is the dependence of the earth upon the sun? It revolves round him as a centre, and thereby receives change of season and distribution of fertility; but is this really dependence? Which of the two bodies is benefited—the earth or the sun? We know of no benefit the sun receives from the earth. It is too far away, and too insignificant, to be even a moon to him, were he anywhere dark enough to require it. It is the earth that is benefited, surely—the earth that is served and waited on! The huge, inanimate, and uninhabitable sun is but a fire to warm it—an automatic link-boy to bear its torch! Can it for a moment be doubted that the sun and moon have a reference to the earth for the benefit of the earth only—whatever benefit, if any, they may elsewhere confer? Even the moon, though reciprocally receiving light from the reflecting surface of the world, is incapable of profiting by it from the want of life upon its barren and uninhabitable disc. To say that other planets are inhabited, and are therefore of equal importance with our own, is to assert a hypothesis—to reason on a speculation. First prove that other planets *are inhabited*, then says the rule of logic argue from the fact. Do not assert or assume in the name of science that which science does not confirm. On this subject science is veraciously and impregnably silent. True—analogy *asks*: Why should Venns, which has an atmosphere, not have inhabitants? but analogy also *answers*: Why should the moon, having a disc toward the earth, not have an atmosphere upon it? Why, in fact, may not inhabitants be wanting in one place, as well as both an atmosphere and inhabitants in another? Who can say positively, after all, *on the basis of science*, or with a shred of evidence at his back, that the world is not the only life-inhabited sphere in the whole universe of created matter?

And what is the importance of mere inanimate matter, as compared with life, with feeling, with mental and moral intelligence?

Such then is the *real* attitude of this great science toward revelation; and any one who dares to assert more in its name belies astronomy, and assails revelation, without the vestige of a cause. The heavens, from their intensest depths and sublimest heights—with their most dazzling splendours, stupendous motions, balancing powers, and forces —and throughout all the explorable immensity of their interminable infinitude, declare the omnipotent and omnipresent power and glory of God, without one breath or suspicion against the integrity of His Word.

TERRESTRIAL PHENOMENA.

CHAPTER XVIII.

Star Showers—Sporadic Shooting Stars, or Meteors, and Star Showers proper—Their chemical composition—Their periodicity—The number of periods—Their composition—Their velocity—The question of their origin—As to whether their origin be from zones occupying interplanetary space, from terrestrial chemistry, cometary influence, or lunar volcanoes—Formation of meteoric bodies, terrestrial chemistry, and origin of the planetary theory—General considerations, objections, and conclusions.

For many reasons, which will be self-apparent as we proceed, the subject of star showers falls to be treated as a terrestrial phenomenon subordinate to the subject of the earth itself. Star showers, whatever may be their origin, are only seen or manifested within the region of our own atmosphere, so far as we know, and it is still a debatable point whether they have any exterior existence or cause. We cannot help looking with some degree of concern on the eagerness of such grave thinkers as those eminent in astronomical science are and necessarily must be, in giving way to the impulse of accepting explanations beyond the range of all experimental testing and all known analogy, for phenomena which are, at all events, quite possibly within the narrow limits of known truth and ascertained chemical operations.

The extensive and systematic sublimation of terrestrial chemistry in modern times, from all the various artificial manipulations of our extended manufactures and arts, combined with the natural exudation of gases from the vital operations of animal and vegetable existence, as well as from processes of decomposition and decay, added to the elements sent aloft into our atmosphere from the still active volcanoes of the world, independent of very many chemical changes for ever in progress, though still little investigated, might have suggested that there must be continually floating in our upper atmosphere a quantity of gaseous elements, the proper region of which is not there, and which are liable at all times to come into contact with other elements for which they have a chemical affinity, and with which they would at once combine, and be precipitated to their proper level again in the solid condition from whence they sprung. And until this source of aërolitic construction has been fully exhausted, we shall, for our own part, hesitate to accept a hypothesis for a truth, and assume a planetary origin for star showers, which, in the best form in which it can yet be stated, is a mere speculation in the dark, without a single link of scientific logic, a single connecting inference, beyond a bare possibility, to bind it together. We have seen too many meteors of a formidable enough character and size moving in a horizontal direction, and at a level which excluded the possibility of any trans-mundane cause to make a scientific *ignis fatuus* of this subject, without being perfectly sure, first of all, of what we are about. Meteoric zones and pocket planets are fine toys for fanciful science; but if such things be, the serious astronomer has to demonstrate their existence by other means, and more irrefragable evidences, than have ever been adduced here. However, we must not forget that we are, in some degree, dealing with the general reader, and introducing him to the science of astronomy as it is; and we will therefore lay this matter impartially, but not without warning against hasty and immature conclusions, before him.

There are sporadic (single or scattered) shooting stars, aërolites, or meteors, as they are variously called; and there are also star showers, or showers of meteors or aërolites, which occur with more or less periodical regularity. Between the chemical composition of the one set of bodies forming the sporadic meteors and the other forming the meteoric showers no distinctive difference has yet been discovered. They both of them consist of combinations of terrestrial elements, of which the best known are aluminium, calcium, carbon, chromium, cobalt, copper, iron, magnesium, manganese, nickel, oxygen, phosphorus, potassium, silicon, sodium, sulphur, tin, titanium; but no elements new to terrestrial chemistry have been found in any case, and only very rarely new combinations or compounds of the elements above named. During the whole year sporadic meteors are falling at the rate of five or six every hour; but during the periodic showers about three times that number may be expected at least, and sometimes a great many more; and though the November star showers have attracted most attention of late years, equally important manifestations have occurred at many other periods of the year; for there are a number of periods on record. Thus the beginning of January; from the middle to the end of April; the end of July; the 10th of August (for many successive years, manifesting a maximum great enough to be called the stream of St. Lawrence); about the 19th of October; and from the 9th to the 12th of December; besides the November period (13th, 14th, and 23rd to 26th)—and many other periods, furnishing a total average of more than four periods per month, have been recorded. And the periodicity is by no means so great as some have assumed, but in almost every case yet observed the recurrence of the shower at the expected period has been more frequently disappointing than otherwise; so that the recurrence is more a fortunate coincidence in connection with predication than a certainty. It is right these things should be mentioned; for while there are upwards of fifty recorded, periods there has been only one of these of late years—the November one—marked by any conspicuous regularity and precision ; so that regularity really is not the rule, but the exception ; and approximate periodicity would be safer language in any sense than precise recurrence. Meteors of the sporadic class may be seen at all altitudes, and not always at a descending angle, but frequently pursuing a horizontal flight, and within a mile of the ground. The meteoric showers, on the other hand, occur at a considerable altitude—the highest level being about seventy-three miles—the range of their visible descent extending to about twenty miles below that. The shower meteors generally proceed from a nearly common centre in all directions downwards, but always downwards, or with a descending angle. This is not precisely what might be expected of bodies whose origin was planetary, and whose projectile force was acquired beyond, and independently of, the range of terrestrial gravitation. Such independent bodies would be much more likely to pass right through our atmosphere in the line of their original impulse, or right downward to the earth, where the body of our sphere was transverse to the line of their impulse; but though they are bodies of considerable weight—Mr. A. Herschel having estimated them to weigh more than two ounces each, while many of them are bodies of great weight and formidable dimensions—nothing of this kind is characteristic of them. It is easy, of course, for impulsive speculation to say what the most profound astronomer cannot prove, that these bodies have a planetary origin, occupying numerous zones in the interplanetary spaces of our system, and travelling, some in the same direction with our planet, some in a direction the very opposite ; that they are so numerous that thirteen hundred or more of them occupy every space-area equal to the dimensions of the earth; and that about four hundred millions of them, on an average, enter our atmosphere every twenty-four hours. Such a statement, as a means of explanation, might be bent in many different ways, and made to account for numerous peculiarities: but then it is a mere hypothesis to begin with, and it is one which does not do away with all difficulties, nor does it present itself unassociated with many serious difficulties of its own. Why, for example, if these meteors have a planetary direction and motion in their zones, do they go in all directions, and with varying rapidity, in our atmosphere? Why are they never seen but within our atmosphere? Why do they not manifest themselves on their first entrance into it? and why is their manifestation that of combustion and extinction only? Is there any reason why a meteoric body consisting of any, or all, of the chemical elements before mentioned in a compounded combination, should take fire from the simple fact of its being seventy-five miles high in the terrestrial atmosphere, and then undergo extinction after a short fiery passage in the same circumstances? If these bodies were chemically combined on entering our atmosphere, there is no reason why they should undergo combustion and subsequent extinction within it. If they are not chemically combined before entering our atmosphere, under what circumstances do they enter it? is it in the form of pieces of pure and separated carbon, iron, phosphorus, manganese, sulphur, magnesium, chromium, titanium, etc.? If so, how do they come to be combined? Or is their external condition that of separated portions or quantities of these elements in a gaseous form, the combination of which is facilitated by an atmospheric medium? If this latter be the explanation, what becomes of the pocket-planet theory in the interplanetary spaces? Then their supposed planetary velocity, which has been calculated at an average of about thirty-five miles per second, though frequently exceeding that, is somewhat perplexing when combined with the want of uniformity in their direction, seeing that the planetary velocity of the earth in its orbit is only about eighteen miles per second. Why bodies with such a velocity should be deflected into various directions by the thinnest and least resisting portion of our atmosphere, is not very easily accounted for on the interplanetary theory. There have been other theories broached, and temporarily entertained, as to the origin of these meteoric bodies—such as, that they have a cometary origin, which, from what we have already seen elsewhere of cometary chemistry, is scarce worth discussing again here ; and also that they proceed from volcanoes in the moon—a good theory, doubtless, if we could discover the lunar volcanoes, and catch the man-of-the-moon firing his mortars at us, or even find—where we at least have volcanoes—that Vesuvius, Hecla, and Etna are, in vindication of the *lex talionis*, engaged in bombarding the moon !—a duty which we hope will not be neglected by our volcanic artillery, should Cynthia be found so belligerent. We need not say that such a theory was never in very serious or extended favour.

That our predilection is in favour of the theory or possibility of the whole phenomena of star showers being of terrestrial origin, and entirely the result of circulating operations in our own chemistry, the reader will probably have anticipated. The reasons for our preference are obvious. The other explanations are hypotheses and speculations only, without a single ascertained certainty at their base. *This has fact to begin with*, and very formidable fact, which must be disposed of or accounted for in some way ; and none other than the meteoric phenomena does account for it, that we know or can conceive of. It is a certainty that there is an extensive circulation of terrestrial chemistry through our atmosphere, from the sublimation of various elements; that, when the operations of animal and vegetable nature, inorganic chemical action, and the manipulations of artificial chemistry are combined, there is a sufficiently abundant source for all our known meteoric displays; and that the natural action of these gases floating in the atmosphere would be to come into frequent contact, and thereupon to combine, from their chemical affinity, and become reduced to the solid state, with the manifestation of combustion, and be precipitated back to the earth, from their consequently recovered density and weight. The periodicity of such displays might be largely accounted for by the periodicity of our seasons, and local circumstances affecting the quantity of such gases floating in the atmosphere at the time, and the periodicity of air currents and operations of temperature in bringing them into contact with each other, etc. Here, at least, we have facts which are ignored by the planetary theory of star showers, and they are facts which must be accounted for in this way, whether they form the whole phenomena of star showers or not, unless another and a better explanation can be suggested, and one which we have yet to hear of.

We are not, on such a question as this, in the condition of having to learn that meteors are formed, or are capable of being formed, in the atmosphere, from the operations of terrestrial chemistry merely. We have definitely ascertained that meteoric bodies are, and may be, formed, independent altogether of any planetary origin or influence, or any communication or connection with interplanetary space or matter. This is definite and appreciable ground on which science cannot err, but may safely stand upright on the basis of demonstration. But if all the astronomers in the world were asked what definite and positive fact exists at the root of the planetary theory—what knowledge of interplanetary space or interplanetary matter can be referred to as a basis of certainty, we fear they would look exceedingly foolish when confronted with existing theories on this subject, if they were to be held as committed to such speculations. It is due to the gravity and importance of science, therefore, to be severe and crucial in our examination of so popular and misleading a question, which, for undisciplined minds, has sufficiently the aspect of dazzle and amazement in itself.

It is true that at the outset of this theory Sir John Herschel had observed, and doubtless with perfect accuracy so far as the observations had then extended, that the meteoric showers appeared to radiate from only one point of space—a strong inducement to believe at the moment that they entered our atmosphere from a region beyond it; and had this observation been confirmed by subsequent and more extended experience, it would have been difficult to resist the conclusion that terrestrial chemistry could not conceivably fix itself and its development in one single region or point of the atmosphere only. But extended observation has shown the reverse of all this, and proved to us that the points of radiation are as various as the periods of the phenomena are numerous; and it is mere puerility, in dealing with such an obvious annihilation of the original basis of this theory, to say that there must be numerous meteoric zones closely coinciding with the orbit of the earth, but some of them revolving round the sun in the same direction with the earth, and some in a retrograde or reverse direction, etc. This is really asking us, because we have discovered one error, to believe ten more, in order that we may get reconciled to it! The idea of meteoric zones running reversely through each other, contains an element of absurdity which had no place in the original condition of the question, when it had as yet been observed that the shower meteors entered or appeared in our atmosphere at one point only. There was nothing incongruous in that. It was the condition of observation at the time. But even then it affected the competency and completeness of our means of explaining the phenomena on the basis and within the limited operation of terrestrial chemistry alone, rather than give demonstration or stability to the planetary theory. Indeed, it was quite as much at variance with the planetary theory as now maintained as it at first appeared to be with the explanation of a terrestrial origin for these phenomena only.

TERRESTRIAL PHENOMENA.

CHAPTER XIX.

The Zodiacal Light—Various explanatory theories of it—The more recent theory connected with the star-shower theory—Laplace's and Mr. Jones's theories—Its double appearance—Another possible cause, with summary of its peculiarities—The Aurora Borealis—Spectra of the Aurora and Zodiacal Light—Similarity of their chemical characteristics—The Aurora and electrical phenomena—Difficulty as to the spectra—Discrepancy between the planetary star-shower theory and the zodiacal spectrum.

One of the more remarkable of the terrestrial phenomena is the Zodiacal Light, especially as no satisfactory explanation of it has yet been given. In the spring, when the twilight is brief, this light appears in the west, shortly after sunset, during March and April; and in autumn, it appears in the east, before sunrise, during September and October, when the dawn is as short as the spring twilight. When the dawn and twilight are of longer duration, it disappears or is invisible. It is certainly a very faint luminosity, for it not only disappears before a long twilight or protracted dawn, but it is equally invisible under the faintest moonlight, or the slightest nocturnal obscurity. It is visible only on clear moonless nights. Its colour is white, and of about the same intensity as the luminosity of the Milky Way; some authorities say of greater intensity, and it inclines to red and yellow toward the horizon. It generally extends to a point upward from the horizon near to the Pleiades, but its extent varies according to circumstances, its base being from eight to thirty degrees, measured transversely to its major axis, which is not at right angles to the horizon, but inclined, so that it coincides more nearly with the earth's orbit, or the ecliptic, than the equator. The portion of it apparent above the horizon is like a portion of an extremely elongated ellipse, or oval, and the major axis of the entire oval, of which it forms a part, always passes through the centre of the sun. The extreme point of its major axis extends from the sun as a centre, to from 50° to upwards of 70°. Its edges are faintly defined, and not very precisely traceable, and it has been said by some observers to have exhibited a minute sparkling appearance in the composition of its light, as well as undulations. Hence it has been said by others to be part of that zone of aërolites or pocket planets, from which we derive the star showers treated of in the preceding chapter. We regret, however, that the planetary origin of the star showers rests on so feeble a basis of independent fact as to make it impossible to offer this explanation to the reader with implicit confidence.

Laplace held the Zodiacal Light to consist of a zone of vapours, which the sun's centrifugal force had projected from his body, when he became condensed from his nebulous condition to his present form and condition, as a luminous sphere; but as we have no authentic grounds for believing that this change in the sun's condition ever took place, but some grave reasons for doubting, if not absolutely denying, it—as will be seen from our remarks on Laplace's theory of the universe—we must, in the meantime, decline to accept this explanation also.

Another theory has been propounded, which ascribes this phenomenon to a vaporous ring belonging to the earth; but this has been so strongly condemned, that we need scarcely enter upon it. It was propounded by the Rev. Mr. Jones, chaplain of an American steam frigate, in 1855, from his observations in latitude 23° 28′ north on two several occasions, when he had the extraordinary spectacle of the Zodiacal Light simultaneously at both the east and west horizons while the sun was at the opposite solstice, in which position the observer has the ecliptic, at midnight, at right angles with his horizon. The phenomenon continued from eleven to one o'clock—an hour before and an hour after midnight—for several nights in succession.

Though unable to receive or give any very strong arguments in favour of Mr. Jones's explanatory theory, we are unable to resist respecting his facts and observations as those of a perfectly competent and credible eye-witness, and they deserve the more consideration that Humboldt, in combating the theory, gave important corroboration of the facts by stating that he too had observed, while at sea in March 1803, a second light in the east contemporaneously with the principal light in the west, and that, at the time, he thought the second light due to reflection. Indeed, the whole facts suggest rather an explanation similar in result to that of Mr. Jones's, though different in precise detail, which yet remains to be considered as a suggestion, and which, whatever confirmation it may receive itself, may be the means of leading to more accurate observations, from whence a correct explanation of the phenomenon may at last be obtained.

It seems to be settled by the facts beyond any doubt, that this zodiacal phenomenon is attendant upon the apparent diurnal motions of the sun. It precedes him at sunrise in autumn, and follows him at sunset in spring. It appears simultaneously both on the eastern and western horizon, according to Humboldt—the weaker manifestation being in the east, while the stronger manifestation is in the west. About midnight, according to Mr. Jones, it appears about equally strong in the west and in the east simultaneously.

And, according to all competent observation, its major axis passes through the sun, and the line of its major axis nearly coincides with the line of the ecliptic. Mr. Jones was impressed with the fact that it was a zone,—a "*nebulous ring with the earth for its centre.*" But why a ring? Its extension was never a complete circle, even within the limits of competent vision and development. It possessed no luminosity of its own; otherwise, what it showed against feeble twilight on the horizon, it could have shown with still more distinctness in mid-heaven, if it extended so far. But is it not possible that a fact, competent within the limits of our own atmosphere, may explain the whole phenomenon? and which if it do not, is yet worthy of careful consideration. We know that the moon's attraction affects the ocean, and produces the phenomena of the tides, and that the conjunction of the sun and moon produces maximum tides; but are we to suppose that the influences which affect the ponderous volume of the world's ocean are powerless over the lighter and more plastic fluid constituting our terrestrial atmosphere? Let us suppose that the sun and moon occasion atmospheric tides as well as aqueous tides, and that the atmosphere, from its more plastic and impressible character, follows the solar and lunar influences more immediately and less tardily than the ocean does, such a volume of upper atmosphere following the sun in conjunction with the moon, and heated by the constant influence of solar radiation, might well be luminous enough to exhibit all the brightness of the Zodiacal Light against a faint and brief twilight or dawn, and might extend far enough to appear above both the eastern and western horizons at midnight, and be partly radiated both by solar and lunar light and refraction; which might at length also explain the sudden undulations of intermittent brightness which Humboldt further observed to traverse the luminous cone; and that its major axis should nearly coincide with the earth's orbit, is also a natural consequence. We place the suggestion merely as such, and for what it is worth, before the reader in the meantime, and without encumbering it with some further conclusions and corroborations which might at present appear plausible and premature, but which at their proper time we are satisfied will give it right to further consideration.

This, then, would be an explanation of the phenomenon of the Zodiacal Light, not precisely the same, nor liable to the same objections, as that suggested by Mr. Jones, but exactly coinciding with the optical impression made on him by what he saw, in all its essential features, and more strictly within the limits of his observation; for there was no zone or ring, and no observer has been able to see a complete zone or ring in any instance. It appears, instead of a ring, to be a luminous tidal action in the upper atmosphere, following the sun, and radiated with his warmth; but so faint in its luminosity as to be visible only under the special conditions in which brief dawns and twilights or midnight darkness are present to reveal it in the region of the heavens in which it appears.

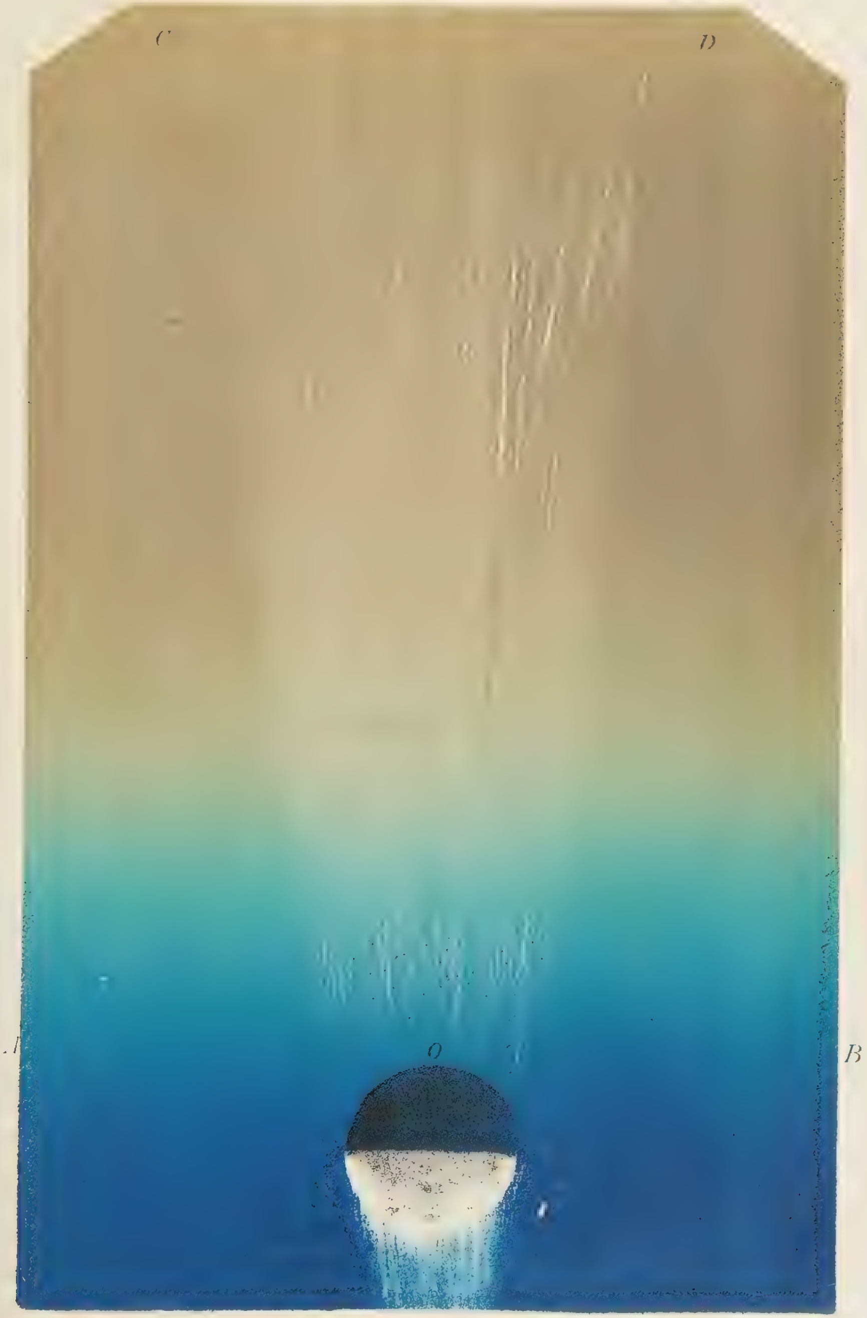
Another terrestrial phenomenon of kindred interest at the present time is the Aurora Borealis, Streamers or Northern Lights, which are now considered to be an electrical manifestation. It is observable in high northern latitudes as well as in the southern hemisphere, and is said to be occasioned by discharges of electricity passing through the highly rarified air of the upper atmosphere; and it is certain that analogous appearances may be produced by passing electrical discharges through rarified air contained in a glass vessel.

The interest of this phenomenon in connection with the subject of the Zodiacal Light is enhanced by the spectrum observations of Professor A. J. Ångström, of Upsala, who, during the winter of 1867-8, observed, on several occasions, the spectrum of the luminous arc, which showed the dark circle always seen in feeble auroras, and is of monochromatic light, exhibiting one brilliant band to the left of the calcium lines The wave length of this band he found, by measurement from the calcium lines, to be equal to 5567. He further observed, by widening the slit, traces of three feeble bands, situated near to F. In March, 1867, he also observed the same bright band in the spectrum of the Zodiacal Light, which he then saw of great intensity; and he adds: "Indeed, during a starlight night, when the sky was almost phosphorescent, I found traces of this band visible from all parts of the heavens. It is a remarkable fact that this bright band does not coincide with any known ray of simple or compound gases I have as yet examined."

The tendency of such a set of facts is, according to the existing state and inferences of spectrum analysis, to lead to the conclusion that the phenomena which yield these spectra characterised by so exceptional a band, are interplanetary in character, and have no connection with terrestrial chemistry. And were it our purpose to favour what may after all be only plausible and immature, though at the moment highly popular, scientific inferences, we might suggest that the envelopment of the earth in the tail of a comet would thoroughly give us all the manifestations of the Aurora, with its flitting corruscations; and that, from the number of comets connected with our system, the manifestations might be quite as frequent as the displays of the Aurora, which we have been so long accustomed to, without our being able to see the heads of the comets at all, or anything but the manifestations of the tail enveloping and stretching beyond us. The accompanying plate will sufficiently explain our meaning, from which it will be seen that the coloured tail of such a comet as we have described in a previous page would, from its great length, extending beyond the earth, exhibit the convergence toward the zenith under the effect of perspective, which is so common a characteristic of the Aurora. But in

Plate IV.

THE EARTH IN A COMET'S TAIL.



Note.— Where there are coloured condensations in the tail [illegible] such an envelopment to an observer at O, on the dark side [illegible] would [illegible] similar to the Aurora and the condensations would be seen [illegible] from the horizon line A B to the zenith C D overhead under the effect of perspective.

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spite of the temptation presented by this line of explanation, we decline to commit ourselves to theories which might be plausible and popular, but unsatisfactory on that very ground, as matters of scientific integrity to ourselves. There are within our reach too many other elements worthy of serious consideration warning us to be careful against so hasty a course.

The tendency of the observations just quoted are to show a close identity between the chemical characteristics, whatever those may be, of the Aurora and the Zodiacal Light, and also to show that the same spectrum and its peculiarities are common to all parts of the terrestrial heavens, under certain conditions. But the tendency of the observations is also to show that we are, as elsewhere observed, dealing here with already partially, if not wholly, analysed light—with the spectrum of part of a spectrum; for monochromatic light, whatever be its colour, is only one of the colours of white light: and until spectrum analysis has made a far more complete and exhaustive investigation of the spectra of spectra, and of all the monochromatic tints of ordinary and special spectra, it cannot be said to come even with its own alphabet competently in its hand to teach us here. We must, first of all, make perfectly sure that there is nothing behind the scenes essential to the truth, before daring to take our stand on a new pedestal of science, which, at the same time, we cannot help wishing may soon become as complete and reliable, in all respects, as it promises to be.

There is no possibility of doubting that the Zodiacal Light is an attendant upon the sun, whether it be as a tidal motion in our upper atmosphere or not; and though the manifestations of the Aurora may be produced artificially by electrical discharges in rarified air, and so may be native to our atmosphere also, it is a difficulty not considered sufficiently in this line of explanation—From whence do the electrical discharges which produce the Aurora come? We should not be inclined to leave such a question in this insulated state under the present condition and self-connecting tendency of the sciences; for the various sciences are daily more and more ceasing to be insulated and unconnected, and are linking themselves to each other at all points, in a system of combined truth and consecutive order, which is not only increasing our confidence, but is affording a means of checking immature and crude conclusions; so that we can sometimes say of a new theory, with the most perfect certainty, that it cannot be true, simply because it is at absolute and irreconcilable conflict with some other department of science now thoroughly established and ascertained.

It is now so well known that the sun has a dominant influence on the electrical changes affecting the earth, and that his light and heat are the means by which this electric influence is chiefly exercised, while electrical science has so nearly settled the point that light, heat, and electricity are one and the same thing under slightly different circumstances of manifestation and action, that we seem at little difficulty for the source of the electrical discharges forming the manifestations of the Aurora. If they be not solar radiation refracted through our upper atmosphere, they may be something of the same kind in a secondary form; namely, the diffusion by electric action of inharmonious temperatures, the disturbance of which is occasioned by the difference between the heated atmosphere which the sun's radiation is directly permeating, and colder regions which night has veiled from his action. Any one who has observed nature ever so carelessly must have noticed the sun's radiance streaming through a rent cloud along the horizon: a daylight aurora, we might almost call it, but inverted and limited by the position and dominant power of the great luminary himself. Any one who has observed a little more closely may have seen the edge of a fleecy cloud sometimes smitten with all the colours of the spectrum, as if its fringe were inlaid with mother-of-pearl or opal; so that, apart even from the common manifestations of the rainbow, nature frequently presents her light in the condition of already accomplished prismatic analysis, and sports herself with the rich tints of the spectrum, leaving us, in such cases, only the spectrum of a spectrum to investigate; or when we deal with monochromatic light, only the spectrum of part of a spectrum: and both the Aurora and the Zodiacal Light are evidently, from their colour, partially, if not wholly, of the latter character, and are revealed to us by radiation generally at something approaching right angles to the lines of their direct radiation, or the direction in which their coruscations proceed,—a fact which cannot be entirely immaterial to the question, as it necessarily complicates it by a double analysis and a reduction of intensity, since Mr. Huggins has himself already discovered that if the intensity of the light of nitrogen in a glowing condition be diminished, only one of a number of characteristic lines is left, and that when the intensity of the hydrogen spectrum is diminished, only the blue line (Fraunhofer's, F.) remains visible. And this suggests a reason from spectrum analysis itself, in addition to others which we will mention in a subsequent place, for our hesitation in accepting the conclusions of Mr. Huggins, that the nebulæ, even when resolved in some instances by the telescope into stars, are, on the authority of spectrum analysis, not discrete stars, but only gaseous luminosities. Their immense distance and diminished light, together with a peculiarity we will mention more fully in its proper place, may account for their spectra not revealing the characteristic lines, but only those lines which indicate a gaseous atmosphere in a state of combustion—their higher luminosity being nearly all the indication of their existence that can reach us from a distance so remote.

There is in relation to the Zodiacal Light and Aurora—and the speculations of spectrum analysis as to the first of these phenomena being identical with the meteoric zone and the source of the star showers—an unaccountable discrepancy somewhere; for while Ångström has found the spectra of the Aurora and the Zodiacal Light to be identical, and that the bright band revealed by these spectra does not coincide with any known simple or compound element, it yet happens that, if the Zodiacal Light be the source of our meteors, no meteor has yet revealed any element unknown to terrestrial chemistry; while, on the other hand, every meteor which has been analysed has revealed many terrestrial elements and compounds of which the zodiacal spectrum gives no indication whatever. Such a fact is a stern warning against precipitate conclusions. We must not therefore be blamed for being cautious.

THE MOON.

CHAPTER XX.

The Moon—Peculiarity of its shape—Variations of the Moon and Planets from the spherical form—Discrepancies in the centrifugal force explanation—Moon's librations—Appearance and character of its surface—Selenography—Comparison of terrestrial and lunar Mountains—Changes in the lunar surface—Moon's elements and other particulars.

There is no getting round the man of the moon. He seems to be so fascinated with mother earth that he could not turn his back upon the old lady for all the sons of Adam; nay, nor to gratify the curiosity of all the daughters of Eve. We cannot, therefore, by any means manage to discover what this ancient adult has behind him. Seriously, the moon presents but one side of its disc to us. The other side we never have seen, and it may be safely said *never will see*. Why is this? Professor Hansen has lately given us a clue to the matter, by being enabled, after careful calculations, to arrive at the conclusion that the moon's centre of gravity does not coincide with the centre of its apparent mass. This conclusion was reached through certain irregularities which he observed in its motion, and which would be fully explained by the assumption that its centre of gravity is 1740 miles beyond the centre of its figure, or further than the apparent centre from us, and that the opposite side of the satellite would therefore be below the mean level taken from the real centre of gravity, and possibly that even air and water might rest on that side, while the side toward us stood out like a vast and rugged mountain above both the ocean and the air.

Are there any allied facts connected with the earth which tend to corroborate this conclusion as to the moon's shape? We think there are, and that they absolutely confirm it. The one side of the moon's disc constantly turned to us, shows that the satellite has a fixed centre with reference to its primary, which this calculation of Professor Hansen would perfectly explain. Suppose that the moon had been in a fluid state when projected and poised in its orbit against the attraction of the earth, the terrestrial attraction would act on the fluid matter of the moon just as the moon acts on the fluid matter or ocean of the earth, but only with greater completeness; for it would act on the entire fluid mass of the moon, while only a portion of the earth is acted upon, namely, the now fluid part, or ocean. When drawn out in this way, the moon could only recover a concentric centre of gravity with reference to its own mass, by acquiring an axial rotation while still in a state of fluidity. After its matter concreted its eccentric centre would become fixed with reference, not to the gravitation of its own mass, but with reference to the attraction of the earth modifying the gravitation of its own mass; and it could not after that acquire an axial rotation upon any axis transverse or inclined to the plane of its orbit round the earth, but only an axial rotation, if there were any cause for it, on its longest diameter, or the line of its radius vector prolonged through its mass, and against this rotation there are impediments. Hence we may conclude that the moon was fluid when first poised in conjunction with the earth, and that it concreted before it had time by rotation upon its axis to balance itself against that attraction of the earth, which drew its matter out, toward us, in the pear shape which Professor Hansen's observations have now for the first time detected. Thus then it is that the moon can only turn one aspect of its surface toward us. And hence, too, we have a confirmation long desired by the present writer of his early conviction that the bulge of planetary equators, and the shortening of their polar axes, are not attributable to centrifugal force, but to the influence of solar attraction, balanced by concentric rectification of each planet's own gravitation achieved by rotation on its axis. True, calculations have been made to show that centrifugal force would satisfactorily explain this spheroidal oblateness. But no calculation of centrifugal force can explain to us why Mercury, with an equatorial rotation only about one-third that of the earth, and a density about one-fourth greater than the earth, should have a polar compression more than ten times greater than the earth. Why Mars, with an equatorial rotation little more than half that of the earth, should have a polar compression more than five times greater than the earth, even recognizing the fact that its density is only about half that of the earth. Or again, why Jupiter, with an equatorial rotation twenty-seven times greater than the earth, and a density of only about one-fifth that of the earth, should have a polar compression only seventeen times greater than the earth. Or, with increasing discrepancy, why Saturn, with an equatorial velocity fifty-five times greater than Mercury, and a density less than a tenth of that of Mercury for centrifugal force to contend against, should have a polar compression little more than three times greater than Mercury. Or finally, to crown the whole question with confusion, why the sun, as we have remarked elsewhere, with an equatorial rotation four times greater than the earth, and a density only one-fourth that of the earth for its centrifugal force to conquer, should have no polar compression at all! Can we command a stronger demonstration than this, that in the conformation of heavenly bodies revolving on their axes, centrifugal force is neither a consistent nor a universal law? No theorising can reconcile these things. Centrifugal force utterly fails to supply a solution of why the great bulge of the earth is not at the equator, but at points which coincide more with the range of the ecliptic, and, therefore, of the sun's perpendicular or direct attraction *throughout the year.*

But centrifugal force seems to have been the only feasible explanation that suggested itself, and the whole arguments and present condition of that theory, when thus correlated with fact, show how far even mathematicians will go out of the way to bolster up a fallacy when they have nothing else to supply a hiatus in the consecutive desiderata of thought. The general reader will see from such an illustration that he must not be too credulous on the subject of scientific authority, but that even he, before quoting too implicitly, must be quite sure he is able to discriminate for himself between scientific proof and scientific assertion.

There is manifestly, therefore, a screw loose in our theoretical astronomy here. How different with Kepler's great laws! If the explanation at present accepted were right, why not—the axial rotation and density of a planet being known—calculate its polar compression as a matter of course, and defy observation to challenge it? but what astronomer would dare to hazard this? We can quite understand the effect of centrifugal force on the orbit of a planet; but on the conformation of the planetary body itself it appears incompatible with cohesion—the retaining power must be overbalanced before centrifugal force can manifest itself there. In the orbit the centrifugal force is greater, and the motion most rapid, when the body is *nearest* its centre of rotation; but in the conformation of the planet the whole theory and experience of the orbit has been inverted to furnish an untenable explanation.

In consequence of the rotation of the observer along with the diurnal motion of the earth, we are enabled to see somewhat more of the moon than one half of the disc, the amount then depending on the latitude of our position, and this arises from the breadth of the earth's surface which we pass over in its rotation during the period when the moon is in view, as that breadth is equivalent to viewing it from two different points situated that distance apart. The greatest value of the diurnal libration, as it is called, arising from this cause, is, however, only about 32″. There are also librations in latitude and longitude, which arise from the disturbing influence of the sun on the moon at various points of her orbit, and which Professor Hansen's investigations tend to explain as in some degree arising from solar attraction on a body with an eccentric centre of gravity. Arago informs us that in consequence of the several librations we are enabled to see about a seven-hundredth part more than the full hemisphere of the moon.

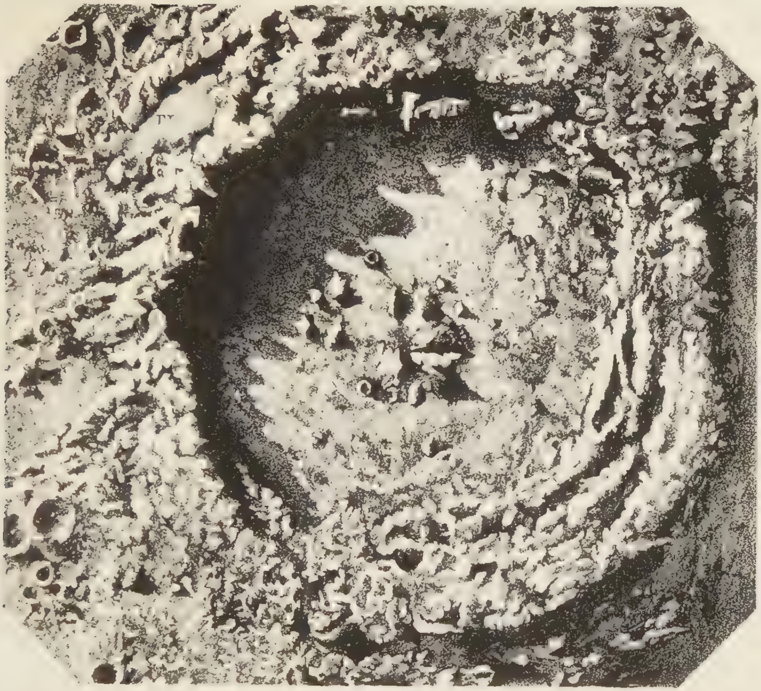
The appearance of the lunar surface presented to us has been the subject of much and careful observation recently, and is deeply interesting. It has all the appearance of a desolate and rugged waste—a steep and precipitous wilderness of bare and blighted mountain crags, with neither atmosphere to soften nor cloud to rest upon them, nor water to invest its sterility with the picturesqueness of a cascade, the mirroring surface of an ocean or a lake, or the refreshing coolness of a single fountain or stream. It is, in the intensest sense, an Arabia Petræa of unmitigated baldness and stony inhospitality—a scathed and stricken solitude, whose catacombs, if it ever had life upon it, have been for ages filled and sealed, and left to perpetual oblivion, without even the whisper of the passing wind to stir or break their silence. Its only visitants are the ghost-like shadows of its hills, beneath which its deep and treeless valleys hide in scowling gloom, chequering its aspect with forbidding darkness. Around and over these, mountain masses rise to an immense height in threatening precipices and ponderous crag refts, and frown upon the deep glens and passes below;

but there are no seasons here with their snows and thaws to disintegrate them from the rugged shoulders of the mountains, or hurl them in avalanches down their massive sides; for the spring and the summer pay their visits here in vain, and the flower season and the wing of the bird of passage must be utterly unknown.

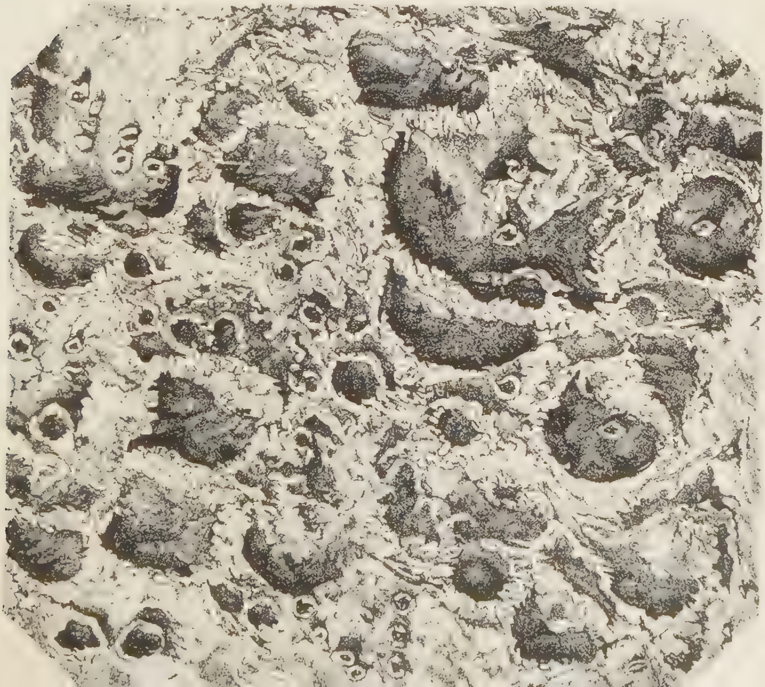
Some of its mountains reach 23,000 feet in height, rising sheer and abrupt from a base or floor of circular depressions, with which the whole face of the hemisphere is studded. These pits range from a few hundreds of yards to more than a hundred miles across, and the lunalogical (geological) names given to the general aspect of the localities are craters, crater mountains, bulwark plains, ring mountains, grey plains, holes, etc., etc. The localities, where distinguished by any speciality of appearance, or conspicuousness of size, height, or depth, have been called after distinguished astronomers and men of science; such as Archimedes, Copernicus, Tycho, etc. Sir John Herschel says that marks of volcanic stratification from successive deposits of lava are evident, along with indications of lava currents flowing outward in all directions. The bottom of the crater called Abategnius is strewed with blocks, seen by Lord Rosse's great reflector, while the ridge of one called Aristyllus is hatched and cracked with deep gullies, radiating toward its centre. The ring called Tycho is near the southern edge of the hemisphere, and is about forty-seven miles in diameter. Its inner side is a sheer precipice of 16,000 feet deep, while its height from the external surface is only 12,000 feet. One writer has said, "The mountains of the moon are not mountains in the common acceptation of the term; they are circular pits, hollowed out into the lunar substance, and surrounded by a ring-shaped elevated border, more or less abrupt and broken. The floor of the pit is in every case depressed far below the general surface of the moon; the ring-shaped ridges are, therefore, much more precipitous in the inner than on the outer side. Very frequently one or more isolated peaks arise from the centres of these depressed floors. The lunar surface is completely studded with circular and rimmed depressions of this nature." In addition to these there are some true mountain chains, which range from north to south to the extent of about 30° of latitude. Generally the hemisphere we have exposed to our view is much in the condition which we may conceive the earth's surface would have presented had it not suffered from aqueous denudation, but were so wholly deprived of ocean and atmosphere that we could see down to the ocean bottoms all round the elevations; for then our mountain ranges would appear probably four times higher than they are, from their having in that case never been denuded above, and never having had the valleys round their base filled up with arenaceous and other detritus. Another circumstance which goes to explain the peculiar elevation of the lunar mountains is the pear-like elongation of the orb toward us, as explained by Professor Hansen. In all particulars these mountains have a purely volcanic aspect, though there are no active volcanoes apparent on the lunar surface. Humboldt has remarked that while the satellite is four times less than the planet, the lunar mountains are $\frac{1}{454}$ of the moon's diameter, and the terrestrial mountains only $\frac{1}{1481}$ of that of the earth. It must be kept in view, however, that terrestrial elevations are measured from the sea level, while these lunar elevations are measured from the unsanded up sea bottom (as it would be, had the moon also an ocean). Were this difference eliminated, the proportions would be much the same in both cases. At one period, and before more competent observation, oceans or seas were supposed to exist on the moon's surface, to which fanciful names were given, such as the Sea of Cold, the Sea of Showers, Mare Serenitatis, the Sea of Nectar, etc., names still used in selenography (lunar geography); but these supposed seas have now been definitively found to be mere depressions of the surface. Dr. Schmidt, of Athens, recently discovered that the Crater Linnæus in the Mare Serenitatis had disappeared, and it has since been observed to be reappearing in a reduced form. Other similar observations have been made of changes, and it is not unreasonable to suppose that there is still in the centre of the moon active volcanic heat and power, though no external manifestation of light or fire is seen, possibly in consequence of there being no atmosphere to sustain combustion, unless a number of brilliant points occasionally visible in the Mare Cresium can be ascribed to interior fire or incandescence—a phenomenon of which we have as yet no other means of satisfactory interpretation. If there be active interior fire, which is by no means improbable, there may be also an exudation of a small amount of gaseous matter occasionally, which would fully account for the supposition of Beer and Mädler, that the moon has a trifling atmosphere—a weak envelope, which from local causes is sometimes dimmed and condensed. A temporary exudation and reabsorption of gases would account for this and a number of other conflicting details of lunar phenomena. Whether there be anything like combustion manifested on the other side, it is impossible to say; but it is scarcely probable that any ocean or air exists on that side, for the elongated shape is the true shape of its equilibrium, as a balance between the attraction of the earth and the moon's own concentric gravitation, and it is not probable that the earth's attraction in fixing this conformation had more power over the solid matter of the moon than over the gases and water on its surface, but would have rather drawn these first, as being lightest and most mobile, toward the terrestrial side of the satellite had they really been there to act on. Neither can

Plate XVIII

LUNAR SURFACE



Copernicus. (from Nasmyth)



South East of Tycho. (from Nasmyth)

we reasonably believe that the moon has ever been inhabited.

We give two illustrations of the moon's surface, Copernicus and Tycho, from the illustrations of Nasmyth.

The mean distance of the moon from the earth is	238,835 miles.
Its greatest distance	251,947 ,,
Its least distance	225,719 ,,

It completes its revolution in its orbit in 27d. 7h. 43m. 11·461s. Its transverse diameter is from 2157 to 2160 miles, and its vertical diameter, according to Professor Hansen, must be about 1740 miles more, as it is probable the whole body of the satellite is concentric, except that portion of it drawn out by the earth's attraction toward us. It has no axis, strictly speaking, and, therefore, no axial rotation, unless the foci of its elliptical orbit round the earth be considered its axis, in which case its revolution round its axis is completed in the same time as its revolution in its orbit. But it must be remembered that such an axis is not within the body of the moon, but external to it, and is not, therefore, a true axis in the sense in which the sun and planets have axes, which are lines passing through one of their diameters, and on which they have a rotation independent of their orbits.

MARS.

CHAPTER XXI.

The elements of Mars—Ocean and land on his surface—Webb's theory of their distribution—Probable error in his first assumption—Atmosphere and cloud on Mars—Whether he be attended by Satellites—Difficulties of the subject—Is Mars inhabited—Moral as well as physical elements in this question—Temperature of Mars, and his chemical condition—Effect of his temperature on his habitability—The argument of the habitability of Planets generally—Contradictions in the argument for habitability—Physical objections—Moral and other objections—Difference in Planetary Chemistry.

The fifth planet of our system is Mars—the fourth of the old planets, and the first planet external to the earth, or further than us from the sun. All the remaining planets are also superior or *exterior* planets.

The mean distance of Mars from the sun is	139,312,226 miles.
His extreme distance being . .	152,284,936 ,,
And his least distance . . .	126,340,516 ,,

His revolution in his orbit is accomplished in 686d. 23h. 30m. 41s.

His diameter is nearly 5,000 miles, with a polar compression—about the exact extent of which there is some variety of estimate—which reduces his axis by about $\frac{1}{56}$th of that amount.

His rotation on his axis is accomplished in 24h. 37m. 23s.; he has therefore the longest day, by more than half an hour, of all the planets.

Mars has no light of his own, but shines like all the other planets by reflection only. This is shown by his phases, which, however, are not like those of the moon or the interior planets, or such as the earth would also exhibit to an observer at the positions of Mars—as Mars never shows the crescent or any other phases beyond a slight gibbosity, or appearance very little less than full. "The red planet Mars," as he has been called, shines with a fiery and glowing lustre when he is in opposition, and at certain points of his orbit has caused surprise by his brightness: his most brilliant positions being those in which he is at the points of his orbit nearest to the sun and to the earth at the same time; that is, when in *perihelion* (nearest to the sun), and simultaneously in *perigee* (nearest to the earth).

Mars, however, is not wholly red, but is a party-coloured planet, having portions of a dull red or orange, and others of a greyish green or bluish hue. Webb concludes, along with many others, that the reddish portions are continents or land, and the greenish portions water and lakes, which infers that, if such be the case, the distribution of land and water on Mars must be the reverse of what it is on the earth; namely, that the seas on Mars are not oceans, but lakes, and that his continents extend much as our oceans do: while our continents are circumscribed like the lakes of Mars into limited areas or islands. This conclusion arises from assuming that the darker spaces possess "the aspect of a fluid absorbent of the solar rays;" and such a conclusion is logical enough, from its premise, but we confess ourselves at a loss to understand why the premise was assumed. Water on the planet Mars, like water everywhere else, we apprehend, would have much of the reflecting character of a mirror—probably in this case over a background of red arenaceous sea-bed—and would give fully reflected light to any observer in a position to receive the reflected rays; while a continent covered, it may be, with vegetation, or even of earth, or other solid matter, or rock, would absorb the rays, and would not reflect with anything like the brilliancy of the ocean surface. On this subject, therefore, we cannot help concluding that the distribution of continents and oceans on the surface of Mars is much the same as that which prevails on the earth, and that the darker parts are solid, and the luminous parts fluid.

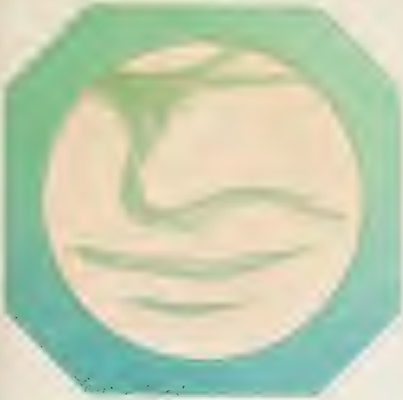
Polar snows, or whiteness so distinct as to resemble them, have also been observed on this remarkable planet, and these whitenesses or snow regions become more circumscribed, as if partially melted, during the polar summer, and extend again during the polar winter; and that at the south pole changes in this way more than that observed at the north pole, which coincides with the known difference of season at each. So that astronomers are justly entitled to consider this phenomenon of snowy arctic regions to be an established fact; for the northern summer of Mars is shorter than the southern—a circumstance accounted for by the eccentricity of his orbit.

The atmosphere of Mars is not considered to be so extensive as was at one time inferred by Cassini, but it is of tolerable density; Beer and Mädler, and also Lockyer, have observed the changing effect of clouds upon its surface. From the extreme distance between its *perigee* and *apogee*, or *nearest* and *furthest* points from the *earth*, the apparent dimensions of Mars undergo very great variations in size at the different points of his orbit—his apparent diameter being reduced to nearly one half at his mean distance, and one-seventh at *apogee*.

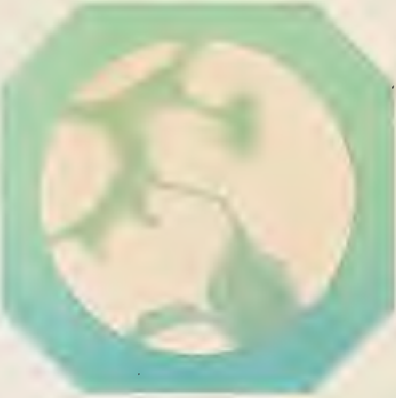
The question whether this planet be attended by any satellite has not been settled. There is certainly as yet no evidence in the negative, as it is doubtful whether our best powers of observation are more than competent to the task of detecting his satellites should they bear the same pro-

Plate XIX

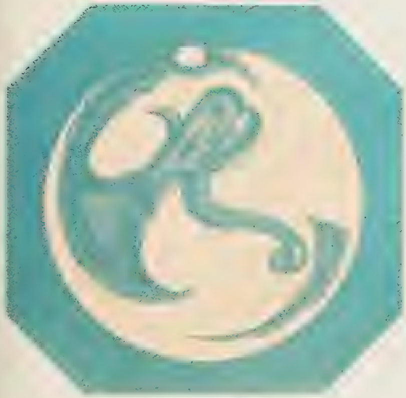
MARS.



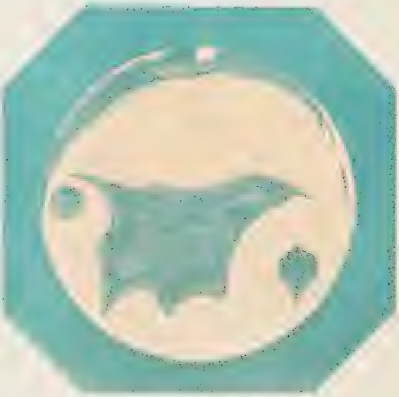
(in 1856)



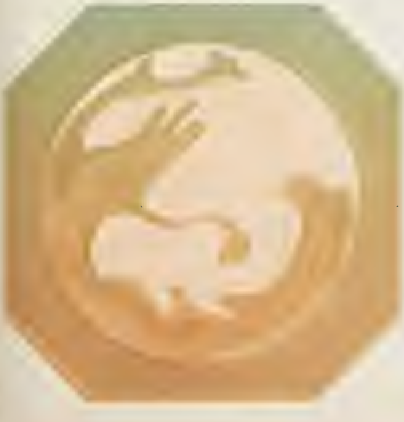
(in 1858)

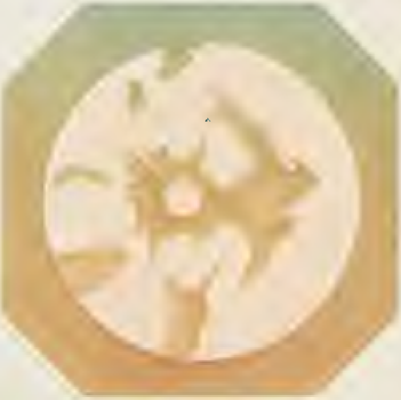


(in 1830)



(in 1862)





P.244. View of Mars by Beer and Mädler & others

portion to his own mass as those of some other planets which we know to be well attended in that way.

Here, then, on the planet Mars everything appears to be fitted up like the world we live in for habitation, if it be not really inhabited. But who can say that it is so? Perhaps some imaginative writer, weary with serving up current crime in cold collations to a surfeited public, to whom sensation and passing events are everything; or finding his vein worked out, will undertake a new feat in future, and people the planet Mars for us with a really good and interesting story. We can assure him we will peruse his three volumes with as profound an interest and as reverent a respect for his veracity as we would anything from that veteran astronomer Sir John Herschel himself on *the same subject*, though we have no intention in saying so to encourage him with the idea that a novelist is a competent astronomer, nor to disparage the venerable reputation of any one bearing the name of Herschel, by supposing there is so much levity in the family as could furnish us with even a tolerable novel. But we have some idea where materials exist, and where they do not, and we should like to know something of the materials which would enable any logical mind, on the faith of bare analogy, to conclude that Mars is inhabited because the earth is. We have, we are fully aware, been guilty of the indiscretion ourselves of mentioning such a thing as vegetation on this planet in our endeavour to invert and rectify what we conceived to be the erroneous conclusion of the Rev. T. W. Webb and others as to the distribution of its land and water; but we hope our readers understood that we were reasoning on the assumed analogy between Mars and the earth, which forms the sole basis of Mr. Webb's and their conclusions, and were therefore dealing, not with premises we admit, but with their premises. It is quite true, *assuming always* Mr. Webb's analogy,—and we hope, in mentioning specially the name of this eminent gentleman, for whose services to astronomy we have the very highest respect, it will not be supposed we have the remotest wish to assail his well-won and distinguished reputation upon a trifling side question to the main science like this,—that we have here in Mars, to all appearance, patches like dark wood-shaded continents, interlaced and bounded by oceans and branching seas with red arenaceous beds; an atmosphere over all, with cloud-like vapours floating through it, and obscuring its landscapes; and arctic and antarctic circles, apparently the chilling confines of periodically increasing and diminishing iceberg and snow. Let us suppose this habitable-looking planet to be inhabited, and take a retrospective and prospective view of its ethical and also its physical condition and circumstances, before we draw the analogy hastily that its inhabitants are beings conceivable by us; or that if they be not so, we are justified in concluding, on the faith of a mere apparent but, as we shall presently show, *absolutely unreal* analogy, that it is inhabited at all. Mars, then, to us is a planet of little less than perpetual sunshine; for we are privileged to view it from above its clouds, and to perceive its existence by looking upon the sunny side of it only. We might, upon the faith of this aspect of it, conclude that it was a perpetual paradise—a region undimmed by sorrow, unobscured by shadow, unvexed by vicissitude. But how fallacious would such a view be! Judging by our assumed analogy, there is beneath all this aspect of sunshine many a chequering shadow; there is on the darker side of this world the night, which gives rest to something that requires rest—whether it be sated pleasure or racking pain, jaded toil or *blasé* indolence. Between the tropics and the poles there are fluctuating temperatures and circulating winds—seasons of beaded sweat and shivering cold. There is here, then, a region of suffering as well as of pleasure, a region which the rains mellow or embitter, which time passes over with change—which death is covering with his sepulchres. If its habitation by vitality be not this, what is it? If there be not here that cold wind which only God tempers to the shorn lamb, how far are we to draw the analogy? and where, by the parity of reasoning with which we start, are we entitled to stop? We are aware that we are dealing with science in these pages, but we are not quite ignorant of metaphysics, nor indifferent to their value. The inner life and consciousness of every man are too real to be left altogether out of a question of this nature, if we are to touch upon it at all. If then, we say, this analogy is to be insisted on, let us reason it out. If this planet be inhabited simply because it appears to resemble ours, why must it not be inhabited in the same way, and under the same apparent conditions? What, then, is the cause of suffering in this distant but kindred world? Do moral responsibility and sin reign there the associate of sorrow, as we know it to be here? and if so, is its fate essentially separated or different from ours? Or why, if it be not so, is that world not death-blighted like our own? Do seasons imply no withering flowers, no sere and falling leaves? If they do, why is man's analogue, the inhabitant of Mars, exempted from the change around him? why there is he alone immortal? These are all questions which must be faced and considered, if we venture to assume the analogy; and they are questions which render the subject a great deal more serious that a mere question of physics. But are we justified in assuming the analogy here even to begin with, any more than we are entitled to do so in the case of the airless and oceanless moon? We venture to think there is no warrant for anything of the kind. The temperature of Mars is at least 57° lower than ours. Its summer heat, therefore, is 13° below the freezing point, and its mean temperature, if taken as high *relatively* as that which is marked temperate on our thermometers, is 2°

the one which He had most wonderfully and pre-eminently endowed? and that the dead and mere inorganic matter of other spheres was of no more importance than so many stones by the wayside in comparison with sentient vitality? It is entirely because we choose to imagine that these other worlds are inhabited that we attach importance to them; and thus it is that the importance of man, as a created being, is denied at the outset of this speculative argument, only that the imaginary distribution of such an insignificant being as this discredited man occupying worlds elsewhere may render these worlds more important than our own. Thus it is that the whole argument is at conflict with itself, and that the insignificance and the importance of such inhabitants as man are insisted on alternately throughout, for the purpose of giving, relatively, insignificance at one place and importance at another to the locality inhabited—the inhabitants anywhere than in our own world being all the while gratuitously assumed! For in the moon we have certainly no inhabitants. We can examine it powerfully enough now, thanks to the enterprise and high intelligence of the late Earl Rosse, to see objects as minute as crag fragments and block masses strewing the bottom of its deep crater pits and valleys, but nothing to indicate the presence of vitality, or the possibility of its existence, so far as we can conceive anything of the conditions of habitability—no air, no water, no circulation of fluids, no fluids to circulate, no imaginable organization or vital motion. In Mars and Jupiter we have apparently different conditions analogous to the distribution of air and water, cloud and rain, and ice and snow, and continent, island, and ocean bed; yet under circumstances in other respects so different as to destroy, on investigation, the whole analogy, so far as the possibility of any form of vitality or any combination of chemistry with which we are acquainted could be insisted on as a consequence, and to enable us to say decisively that the atmosphere and fluids of these planets cannot be of the same chemical composition with our own. True, the idea of internal heat may be suggested as compensating for the remoteness of these bodies from the sun, and the suggestion will appear quite satisfactory to those who will not take the pains to investigate the practical value, or rather the want of value, of the hypothesis. To compensate the habitable surface of Jupiter for the deficiency of its temperature as compared with the earth, in consequence of greater remoteness from the sun—that is, to bring the inherent temperature up to an equality with the earth—would require at Jupiter's distance nine hundred and forty degrees added to the earth's inherent temperature. In other words, if the earth were removed the length of Jupiter from the sun, its present surface temperature, at the point marked temperate on Fahrenheit, would require 940° of interior temperature communicated to the earth's crust to maintain it as it is, making thereby the point temperate, now marked 55°, represent 995°, or a surface heat of its own 783° above the boiling point of water. Can we suppose, under such circumstances, that the circulating elements of Jupiter's surface are the same as those of the earth? If lead, mercury, and tin were on the surface of Jupiter, they would all be boiling long before the temperature was reached, which required to be supplied from the interior to compensate the want of solar heat; and at its tropical summer heat the equatorial region of this planet, if composed of chemistry similar to our own, ought to be incandescent. Let us endeavour not to be misunderstood: we are dealing with the difference between the temperature of solar heat at the distances of the Earth, of Mars, and of Jupiter respectively, and the effect of adding or withdrawing their respective differences of temperature on chemistry such as that of the earth's crust, and atmosphere, and ocean; and we say that if the earth were removed to the distance of Mars or Jupiter, it would, over its whole surface, be reduced to a state of perpetual frost. While if Mars were brought as near to the sun as the earth, its crust would be rendered incandescent; and Jupiter, at the same nearness, would be set on fire; and so, in like manner, the earth brought as near to the sun as Venus, Mercury, or Vulcan would be set on fire.

These facts will show how cautious mere speculation requires to be on such subjects, and what a series of absurdities and contradictions the obtrusive repetition of this insignificant but strangely all-important Ego,—the universal and indispensable Inhabitant, may lead us. And what, after all, is the necessity for this supposed occupant everywhere? The Creator of these worlds, we may reasonably and reverentially conclude, created them for His own high pleasure and purpose; and man or his analogue is nowhere necessary to God, nor, we deeply fear, any great source of satisfaction or pleasure to his Maker. Why must we assume then that he, and such as he, are to be found inhabiting and in full possession of the Almighty's works everywhere? As if everything were done for his pleasure and accommodation only! All the moral considerations—and we cannot ignore them as some reasoners seem so easily to do—appear to us to be decisively against the repetition at all points of a being, or anything bearing the slightest affinity to a being, who, with all the highest gifts of communicated intelligence and conscious dependence for daily existence and mercy, insults the name and authority of his Lord at all times, and even insolently denies His existence. We should conclude, rather, that no more of this weed was sown, as a moral poison through the universe, than necessary.

The density of Jupiter, we have good reasons for knowing, is little more than one-fifth that of the earth, but the earth's chemistry removed to the distance of Jupiter, and reduced to his temperature in consequence, would undergo such a degree of compression and condensation as would certainly increase in a very material degree its density. We, therefore, cannot, on mere assumption, believe the prevailing chemistry of Jupiter to be the same as that of the earth. Neither can we do so of the prevailing chemistry of Mars.

The density of the earth is as 5·67; that of Mars, 2·93; that of Jupiter, 1·23; the density of water being taken as 1·00. These facts go to prove that though similar chemical elements may exist in all these planets, the same chemical proportions and arrangement of them cannot prevail.

THE PLANETOIDS.

CHAPTER XXII.

Discoveries of Ceres, Pallas, Juno, and Vesta—Discovery, after thirty-eight years' interval, of Astræa by Hencke—Discoveries of one or more new Planetoids every year after that—One hundred and six Planetoids discovered up to 1869—What led to their discovery—Bode's law—Kepler's previous prediction—An astronomical council held, and a determination to explore—List of Planetoids since discovered—Their position and inclination to the Ecliptic—Planetary Orbits generally, and the Ecliptic—Nodes—Range of the Planetoids between Mars and Jupiter—Their size and aspect—Theory of Olbers as to their formation—Objections to his theory—The number of Planetoids supposed to be still undiscovered.

On the second new year's day of the present century, 1st January, 1801, Piazzi, at Palermo, discovered the first minor planet or planetoid, which was named Ceres. In about six years afterward there followed the discovery in succession of Pallas, Juno, and Vesta—Juno by Harding, and Pallas and Vesta by Olbers. Thirty-eight years passed over this region of astronomy, when, on 8th December, 1845, Astræa was discovered by Hencke; and then, in about a year and a half later, Hebe, by the same discoverer. Then, in the same year with these last, 1847, Isis and Flora by Hind; and since then not a single year has passed without adding one or more minor planets to our knowledge, till they, early in 1869, had reached the long list of one hundred and six. And when discoveries of this description, which have at last become commonplace, may terminate, it is difficult to say, so long as we do not know the attainable limit of telescopic power. That there are still numerous planetoids unknown is considered as quite certain, but the difficulty of detecting them is increasing, in consequence of their diminution in size.

Strange circumstances led to these discoveries at the earliest stage of them. First came Bode's law—a law no longer—pointing out a blank space in our planetary system, the startling announcement of a planet lost, stolen, or strayed! Wanted—a planet to fill a situation!!

To enable the reader to understand the position, we must crave his patience while we make him acquainted with Bode's law, which fortunately is a very simple affair, and besides has the advantage and still remaining value of being a very convenient mode of finding the heliocentric distances of all the planets but two—those of Vulcan and Neptune, so that we have the relative distances of eight out of ten of the planets, including the average distance of the planetoids, by it. If, then, the reader will be kind enough to write down, at any time when he wishes to remember the relative distances of these eight planets and the planetoids, first a cipher, then the number 3, and then the double of it, and of each new number added to the series after it, till he has nine sets of figures, he will find the following results:—

	0	3	6	12	24	48	96	192	384
Then add 4 to each:	4	4	4	4	4	4	4	4	4
Then divide each by 10 thus: 10)	4	7	10	16	28	52	100	196	388
And you have decimally:	·4	·7	1·0	1·6	2·8	5·2	10·0	19·6	38·8
Being the relative distances of:	Mercury	Venus	Earth	Mars	(?)	Jupiter	Saturn	Uranus	Neptune

The (?) under the fifth number of the series was just the question before the discovery of the planetoids,—"What has become of the planet which should be here?" And singularly enough the discovery of the planetoids answered the inquiry with "*here!*" and at the same time, by their diminutive form and eccentric orbits, and their exceptional inclination to the plane of the ecliptic, explained the difficulty which had impeded their discovery. A singular enough coincidence also in the figures is that the earth's position in the question is that of *unity*—the position in which it is so often placed in astronomical estimates and comparisons. Truly, if there be not law, there is something like natural magic in Bode's figures. Kepler had long predicted the existence of a new planet in the interplanetary space between Mars and Jupiter, because it formed a blank in the planetary distances then known, which were only six, viz., Mercury, Venus, Terra, Mars, Jupiter, and Saturn. But it was the great discovery by Sir William Herschel, of Uranus, 1781, and the fact that the distance of the new planet coincided with the distances of the others already known, that led to a reconsideration of the subject, stimulated by new-awakened zeal to discover some law which might be found to regulate the planetary distances, which led to the discovery by Professor Bode, not of a law, but of a remarkable empirical coincidence. Zach was so much impressed with Bode's apparent law that he even computed the distance and period of the interplanetary stranger. Still the missing planet maintained a strict incognito. Science was dissatisfied. A congress of the disaffected astronomers was held at Lilienthal in 1800, when six eminent observers attended, and it was resolved to devote a persevering search and scrutiny to the subject. Piazzi was one of the searchers, and, as we have mentioned, the first successful observer, and thus did an empirical coincidence acquire the importance of a law, for it may be fairly said that it accomplished as much as a law could have done in the circumstances. Unfortunately for its reputation and strict accuracy, the subsequent discoveries of Neptune and Vulcan have been made, and have given it the *coup-de-grâce.* The blank or defect now is no longer in the interplanetary spaces; the planets have been intruded on, and have turned unkindly against the law. After the discovery of Ceres there followed very soon the three others, Pallas and Vesta by Dr. Olbers, at Bremen, and intermediately between them Juno by Harding, at Lilienthal, the place of the astronomical council of 1800, four years previously. We have already mentioned the discovery of four others—Astræa, Hebe, Isis, and Flora, after an interval of about thirty-eight years—Astrea in 1845, and the last three in 1847. In 1848, Metis was discovered; in 1849, Hygeia; in 1850, Parthenope, Victoria, and Eugeria; in 1851, Irene and Eunomia; in 1852 there were *eight* discovered—viz., Psyche, Metis, Melpomene, Fortuna, Massilia, Lutetia, Calliope, and Thalia; in 1853, *four* —Themis, Phocea, Proserpine, and Euterpe; in 1854, *six*—Bellona, Amphitrite, Urania, Euphrosyne, Pomona, and Polyhymnia; in 1855, *four*—Circe, Leucothea, Atalanta, and Fides; in 1856, *five*—Leda, Lætitia, Harmonia, Daphne, and Isis; in 1857, *nine*—Ariadne, Nysa, Eugenia, Hestia, Melete, Aglaia, Doris, Pales, and Virginia; in 1858, *five*—Neumausa, Europa, Calypso, Alexandra, and Pandora; in 1859, *one*—Mnemosyne; in 1860, *five*—Concordia, Danaë, Olympia, Erato, and Echo; in 1861 *ten* (the largest number of any year)—Ausonia, Angelina, Cybele, Maia, Asia, Hesperia, Leto, Panopea, Feronia, and Niobe; in 1862, *five*—Clytie, Galatea, Eurydice, Freia, and Frigga; in 1863, *two*—Diana and Eurynome; in 1864, *three*—Sappho, Terpsichore, and Alcmene; in 1865, *three*—Beatrix, Clio, and Io; in 1866, *six*—Semele, Sylvia, Thisbe, Julia, Antiope, and Ægina. Since then upwards of fourteen more have been discovered, some of which have not yet received names. Those named being the 92nd, Undina; 95th, Arethusa; 96th, Ægle; 97th, Clotho; 98th, Ianthe; 100th, Hecate; and 101st, Helena. Indeed, their names are now as difficult a feat for mnemonics to deal with as were the names of the constellations at one time, when, as Sir William Herschel remarked, the ambition of each amateur in astronomy was to map out an unappropriated star group into something like an imaginary resemblance to a kind of figure, and thence claim distinction for being the *discoverer of a new constellation!* Astronomers have since judiciously dispensed with most of these new discoveries, and retained only such of the older or more necessary ones as tend to facilitate star mapping and localization as guides to identification. The discovery of the planetoids, however, must not be so regarded. They are real discoveries, involving perseverance and true astronomical qualities of the higher order. It is only to their number, which is getting inconvenient, that our remarks are applied. From this cause astronomers will probably, in a short time, be compelled in practice to dispense altogether with their names, as they have already begun in some measure to do, by adopting their number in the order of discovery instead, inscribing the number in a small circle for the sake of distinguishing it from other numbers, thus—① Ceres, ○ Vesta, ⑨, ⑳, (100), etc.

The greater number of these planetoids are somewhat nearer to Mars than the exact intermediate distance between him and Jupiter, and we may conclude that very few of them will be found in orbits nearer to Jupiter than to Mars. The nearest and furthest distances of these orbits from each other, at the points where they are nearest, may be about 120,000,000 miles. This may be considered the diameter of the range they occupy in the plane of the ecliptic between Mars and Jupiter. It must not, however, be understood from this that their orbits lie in the plane of the ecliptic. In this respect they differ very remarkably from all other planets. And here let the reader understand that the plane of the ecliptic is an extension of that circle into sideral space, dividing the heavens into two hemispheres, as was already mentioned of the equator, in treating of the Pole Star. The plane of the ecliptic is inclined to that of the equator about 24°. The northern side of the ecliptic—the Pole Star of which would at present be *delta* (δ) Draconis, the nearest conspicuous star to it—is, in astronomical language, considered the upper side of the plane of the ecliptic. This arises naturally from its being the side upward to all European astronomy, while the southern side is the antipodes, and therefore the under side to European observers. The earth is the only planet which revolves round the sun strictly in the plane of the ecliptic, for the simple reason that the ecliptic, as delineated on our globes, is the line of the earth's orbit round the sun drawn upon the figure of the earth itself. The plane of our ecliptic, therefore, is the plane of the earth's orbit; and, as all other planets have their orbits more or less inclined to that of the earth, the ecliptic of every other planet is different from that of the earth. We speak, however, in astronomy of but one ecliptic, that of the earth; for only one standard can be made use of with advantage for such a purpose; and as the orbits of other planets differ in their plane from our own, so they are spoken of as inclined to the ecliptic. Every planetary orbit inclined to the plane of the ecliptic must pass through the outward extension of that plane at two points in its course round the sun, and must therefore be partially on the north, and partially on the south side of the ecliptic. In passing through the plane of the ecliptic southward it descends, and in passing northward it ascends, because the planet thereby descends or ascends in the northern sideral hemisphere; that is, it sinks downward to or rises above our horizon. The points at which it so passes through the plane of the ecliptic are called its nodes (from *nodus*, a knot), a not very happy expression, but now so well established in use and general acceptance that its practical meaning may be interpreted as the two points of intersection of any orbit, planetary or cometary, with the ecliptic, and the nodes are called ascending or descending nodes, according as the planetary or cometary bodies at those nodes or points of intersection are coming up northwards, or rising in the northern hemisphere, or going down southwards, or descending from the northern hemisphere. The ascending node in practical astronomy is indicated by the sign ☊, and the descending node by the same sign inverted ☋. The straight line of direction between the nodes is called *the line of the nodes.* The orbits of all the major planets coincide with the orbit of the earth, and consequently with the plane of the ecliptic, so nearly that the deviation of the minor planets in this respect was one cause why they were so long in being discovered, and why looking for the one missing planet, supposed to exist before they were discovered, failed to find either it or them, because the search was confined to the neighbourhood of the plane of the ecliptic—a region from which the planetoids are considerably removed during the greatest portion of their orbitual motion.

We have not yet full particulars of the elements of the last fourteen planetoids; for these elements are not fully ascertained and calculated simultaneously with the discovery of each planetoid itself; but one of the least inclined orbits to the ecliptic may be considered to be that of Massilia, which is about two-thirds of a degree, while one of the most inclined is that of Pallas, the largest of all the planetoids, whose diameter is about 600 miles, and the inclination of whose orbit is about 34° more than that of Massilia. Flora the 8th is one of the nearest to Mars; and Cybele the 65th one of the nearest to Jupiter. The semi axis major, or mean distance of Flora is 2·2014 times that of the earth, according to the calculations of Brünnow, or about 201,274,000 miles from the sun. That of Cybele is 3·4205 times that of the earth, or about 312,737,000 miles, as calculated by Fritsche;

showing a mean distance between these two minor planets of 111,463,000 miles. In other words, they are further apart from each other than the earth is from the sun by about twenty millions of miles. We shall see from this fact, when we come to deal with the speculation of Olbers, as to the formation of the planetoids, how utterly impossible and extravagant his theory of their formation is.

The brightest of all the planetoids is Vesta, this brilliant little planet being, by its pale yellow light, visible in a pure atmosphere even to the naked eye, though at a mean distance of 223,000,000 miles from the sun. It has a diameter of only about 300 miles, according to Mädler, or about one-seventh part of the diameter of the moon, and is about a three hundred and forty-third part of the moon in volume. The faintest of the planetoids it would be difficult to name in the present state of our knowledge. They vary much also in the eccentricity of their orbits, as well as in their magnitude. Some of them are so small, that they would make a mean appearance as islands in some of our lesser seas; many of them being less in disc than the surface of the Isle of Man. The conspicuous and beautiful Vesta, seen so far, has a disc only about a third greater than the surface of the Island of Hayti or St. Domingo; and even the largest of them, Pallas, has a disc only about equal to the area of Madagascar.

Ceres is sometimes seen by the naked eye, and Pallas and Juno at perigee are like seventh and eighth magnitude stars; while Vesta, from its superior brightness, becomes as prominent as a star of the sixth magnitude. Juno and Ceres are reddish in colour, and Pallas is yellowish, like Vesta, though not so nearly white. It was suspected by Sir William Herschel, at one time, that Ceres had two satellites; but, though there is nothing impossible in such a suggestion, it is quite as likely that what Sir William saw may have been two of the smaller planetoids nearly in conjunction with Ceres.

During the brief period when Ceres was the only planetoid known, the astronomical world felt satisfied that the missing planet of Kepler and Bode had at length been discovered, and the requirement of astronomical arrangement fully complied with. But when, about fifteen months afterwards, Olbers added Pallas to the discovery of Piazzi, wonder and perplexity fell upon the mind, as if it had discovered too much! At length Olbers suggested the explanation that a great planet had been burst or rent asunder by some internal convulsion, and that these minor planets were fragments of the orginally massive whole. Since then, of course, many other explanations, varying upon that of Olbers, have been added to the subject, such as the shock of a comet, etc.; and to the present time the theory of Olbers is seriously discussed by many who do not appear to take a very comprehensive view of the existing facts. It is quite true that an explosion, bursting up a planet, would be likely to throw the fragments into totally different orbits from that of the original sphere, so broken up, and that the fragments would have different directions, as well as different velocities and ellipticities, such as we find the planetoids to possess; but then it is not possible that an explosion powerful enough to throw portions of a sphere one hundred and eleven millions of miles from each other in their mean distance from the sun, or a greater distance by twenty millions of miles than that of the earth from the sun, should have exploded only in one direction, so that none of the planetoids should have reverse orbits from the others. An explosion explodes in every direction, though it will throw some portions of the exploded matter further distances and with greater velocity than others. And nothing in the appearance of the planetoids themselves gives the slightest reason for supposing that they were not created just as they are, and their orbits as distinctively arranged and balanced as those of any others of the planets. They are not fragments in any sense of the word, but are round spherical bodies, or spheroids, like the earth, Mars, Venus, and other planets of the larger class; and from their position to us they doubtless all of them present the gibbous phases of the exterior planets, though our observation is not yet refined enough to have detected the fact. The other alternative, of cometary collision, is a still wilder speculation ; for while we know of no cometary matter capable of causing such a catastrophe to any of the planets, and feel in no danger whatever of such a result, it is not conceivable that collision with any body solid enough to achieve the shattering of the supposed original planet into fragments should have thrown them into such widely dispersed orbits as they occupy, with many and various directions and velocities. In no conceivable direction in which the force of the collision could strike the supposed planet, could it have caused the present state of the dispersion ; and though it is quite true that these orbits are as beautifully interlaced as a sphere of network, so that, as D'Arrest has said, if they were figured under the form of material rings, these rings would be found so entangled as to make it possible that taking hold of any one of them all the others would be lifted : yet this is not an evidence of their being fragments resulting from the disaster of a collision, which would, on the contrary, have resulted in an exact combination of the two forces—that of the planet in its orbit, and that of the force of the collision—producing a third force and direction the exact measure of both. But really speculation in this way is of very little value ; for it can never positively attain to anything like certainty or fact, though it is perhaps pleasant to some minds not to be content with a bare truth just as it is, but to have a halo of imagination always floating and dreaming round it. Such things, however, are poetry, not science ; and the poetic mind of all others requires to be strictly disciplined, for it is capable of great self-deception.

The periods of the planetoids in their orbits range from about three and one-fourth years to about six and three-fifths years—periods which, on comparing them with those of Mars within, and Jupiter beyond them, apply rather to their position than to any artificial force, either of explosion or collision, and in this respect they manifest a conformity with other planetary experience, which is totally incompatible with the idea of violent disturbance on either theory.

A progressive diminution in the size of the planetoids has been manifested as the discovery of them has increased, so that we may expect to come at length to bodies so small as to render further discovery of them beyond our present telescopic powers. The discoveries of the later of them, therefore, though not possessing the distinguishing merit and novelty of the first discoveries in every respect, have still a peculiar merit of their own, arising from the continually increasing difficulty of their detection—involving all the skill employed by the first discoverers with much more minute and careful pains. To what extent discoverers may proceed still it is difficult to say. A limit must exist, but, according to Le Verrier, it is a very wide one, if he be at all correct in supposing that we have as yet discovered only about one seventeen-hundredth part of them, in point of volume or mass. This would imply, if they go on diminishing in size, that, in addition to the hundred already discovered, we may have from three to four hundred thousand of them still to look for. Such a calculation, however, is somewhat speculative, being based a good deal on Olbers' theory of a broken-up great planet, at least as large as the earth, and as dense. There is no more reason to support the basis of such a calculation than there would have been to justify the conclusion, if it had been come to before the discovery of Saturn or Uranus, that they must be at least as large and dense as Jupiter—a conclusion which the discoveries of these bodies would have demonstrated to be a singular and gratuitous fallacy.

JUPITER.

CHAPTER XXIII.

The elements of Jupiter—His Atmosphere and Clouds—His Satellites and their elements—Eclipses of his Satellites—Transits of his Satellites—Peculiar arrangement of Jupiter's Clouds into bands—Probable effect of his rapid rotation on his axis on the shape of his Clouds, combined with the effect of solar attraction.

We now come to describe the fifth of the old planets, Jupiter—the seventh now, enumerating Vulcan and taking the planetoids as representing one. We have made some mention of this the greatest planet of our system in a preceding chapter.

The mean distance of Jupiter from the sun is - - - -	475,693,149 miles.
The extreme distance - - -	498,603,768 ,,
The least distance - - -	452,782,530 ,,
His diameter is - - - -	88,390 ,,

with a polar compression of from one-sixteenth to one-seventeenth part.

His revolution in his orbit is accomplished in about 11 years 217_3 days. His rotation on his axis is completed in 9h. 55m. 25s.

To give the reader some idea of the size of this immense planet we may mention that if it occupied the same position as the earth, we on its surface would be nearly one-fifth nearer to the moon than we are at present, and the disc of that body would be very much increased in its apparent magnitude.

Jupiter is considered to have a very dense atmosphere, full of long belts of cloud divided by longitudinal ruts or streaks through which his body is seen. These are undergoing such continuous changes as to leave no doubt that they are composed of highly mobile and variable matter, such as cloud of some kind floating in a gaseous medium might be expected to be, and their variation is generally from a few broad to an increased number of narrow strips; their change being sometimes accomplished with great rapidity, at other times being slow enough to indicate a pretty equable condition of his atmosphere for months together. Slight colouration may be seen on these clouds, though their prevalent hue is grey as contrasted with the somewhat reddish or rose-tinted appearance of the planet's self. This planet changes considerably in apparent magnitude at the points of perigee and apogee. At the former his apparent diameter is about one-third greater than at his greatest distance from us. He is about fourteen hundred times larger than the world.

A phenomenon of considerable perplexity marks the question of the rate at which Jupiter revolves on his axis, and forms a subject of curiosity and interest besides, namely, the appearance at times of spots on the face of this planet. These spots are not very often seen; but when observed, Cassini and others took occasion, from their motion along the disc, to deduce the planet's axial rotation. A discrepancy between some of the later observations, however, has led to the suspicion that these spots are not permanent nor locally fixed on the surface of the planet, but are liable to change, or proper motion of their own. Dark spots have been observed by Hooke, Dawes, Airy, and others; and luminous spots were also observed in 1849 by Dawes, and on two subsequent occasions by Lassell. They appeared to have a rounded character, which is so peculiar as to render it impossible to assign to them the character of islands; and their nature and appearance does not seem referable to any analogy, so that their character is still unknown.

Jupiter is attended by four satellites, named respectively Io, Europa, Ganymede, and Callisto. All these are larger than our moon, except Europa, which is slightly smaller. The diameter of the moon, as we have already mentioned, is 2,160 miles; Io is 2,352 miles; Europa, 2,099 miles; Ganymede, 3,436 miles; and Callisto, 2,929 miles in diameter. The mean distances of these satellites from Jupiter, and their periods in their orbits, are as follows:—

	Distance in miles.	Sideral period.
1. Io - - - -	267,380	1d. 18h. 28m.
2. Europa - - -	425,156	3d. 13h. 34m.
3. Ganymede - -	678,393	7d. 3h. 43m.
4. Callisto - - -	1,192,823	19d. 16h. 32m.
With these compare the moon in regard to the same particulars	238,833	27d. 7h. 43m.

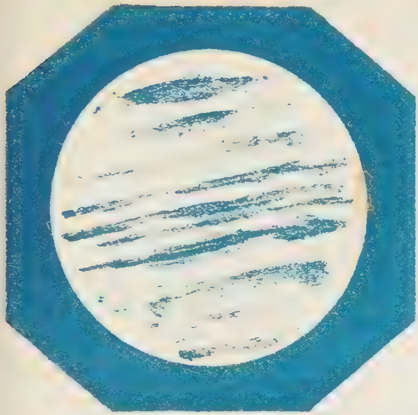
It will be seen from this that the satellites of Jupiter move with immense rapidity compared with the moon.

The eclipses of these satellites in the umbra of Jupiter are a beautiful feature of the *Jovian* system, and they have been sometimes seen even with the naked eye. From the rapidity with which they perform their orbitual revolution, these eclipses take place very frequently, the three first more particularly so; the eclipse of Io occurs once every two days, and lasts nearly two hours and a half—the eclipse of Europa taking place once within every four days, and enduring nearly three hours, while Ganymede is eclipsed once every eight days, with a duration of the eclipse amounting to nearly four hours. The duration of these eclipses may appear long, considering the great rapidity of the satellites in their orbitual motion; but it must be remembered that the mass of Jupiter throws a very broad shadow behind him, and one which, from his size as compared with any of the other planets, passes far into space before it comes to a point. The transits of the satellites across the disc of the planet are likewise of interest. The satellites are also frequently concealed from our view behind the great mass of the planet, without their passing through his shadow; these are called occultations. It is their nearness to Jupiter himself which renders it so difficult to perceive them with the naked eye, as their luminosity is equal to that of stars of about the sixth magnitude. The transits have a peculiar difference from transits of the inferior planets Venus and Mercury across the sun. In the latter case a dark round spot is projected against the sun's disc; in the former, a round luminous spot passes across the disc of Jupiter, preceded or followed by its shadow, when not in actual conjunction, which appears as a round dark spot on the disc, as if the transits were by two bodies instead of one—a dark and a luminous one at the same time—the dark spot being considerably less than the luminous one, or satellite, and caused by the contraction or tapering of the cone of the satellite's umbra before it reaches his disc. Whether there be any spots on the surface of Jupiter's satellites such as those on the moon, has not yet been fully determined. Analogy would lead us to conclude there are, and some peculiarities noticed during transits have educed probabilities of a more positive character, in the same direction. The third and fourth satellites have been seen to be dusky and dark-looking, occasionally, during a transit, as if they did not always present the same side or the same aspect and character of disc; and when these appearances are more fully observed with optical power adequate to the task, we may find that they have, in addition to what we already know of them, a rotation on an axis interior to their own bodies, like the planets, and are, in this respect, different from our own moon, which, to an external observer of it during its transits of the earth's disc, would always present the same side, *i.e.* the side opposite to that presented to us; and which, as already explained, we never see.

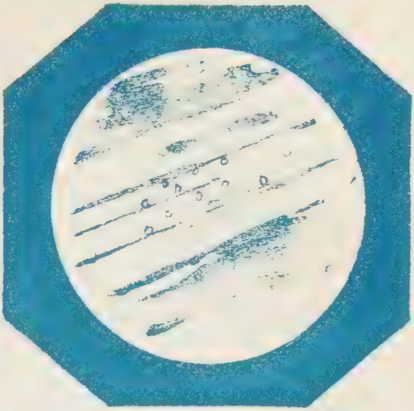
But why are the clouds—for we must assume them to be such, whatever be their chemical character—of Jupiter drawn out into bandages or ribbon-like stripes transverse to his axis and parallel with the plane of his equator? Are there no connecting or correlative phenomena or peculiarities of this great planet to throw any light upon this subject, and show us, perhaps, also why these clouds never reach the edge of his disc, nor seem to pass round him, as if the belting form of them were not the same on both sides? We think there are a few facts which deserve consideration, at least in the natural juxta-position in which we find them. Jupiter is a planet of immense size, with a rapid rotation on his axis—more than twice as rapid as that of the earth—and, in consequence of his greater dimensions, having a velocity at the surface of his equator about twenty-five times as rapid as that of the earth at the same part of its surface. He has, as we have said, four satellites performing rapid orbits round him, and he has the dominant influence of the sun on his great mass to create tides in his ocean and air, such as are found to prevail on the surface of the earth by the influence of the moon in conjunction with the sun. Is it too much to suppose that the influence of the sun and satellites on his atmosphere, combined with his own rapid rotation on his axis, has a tendency to make the tidal action on his ocean, and a corresponding action on his air and clouds, twenty-five times as rapid as that of the earth, and to draw out both cloud and tidal elevation into such force and velocity as to produce long protracted lines of both, instead of such diffused tidal and atmospheric action as we are accustomed to? It is singular, at all events, that Uranus, which we are about to describe, is a planet of rapid axial rotation also, and has the same striped appearances; while Mars, which is a slow-going planet like our own, has not. Then, as to the reason why these cloud-stripes do not pass round the edge of the disc, let us bear in mind that the attraction of all the four satellites of Jupiter has a trifling power on his immense surface compared with the power of the moon over that of the earth ; for the moon may be considered roughly to be about one sixty-fourth part of the earth in volume, while all the four satellites of Jupiter together are not a millionth part of his volume : consequently here the dominant attractive power on Jupiter's tide must be that of the sun; and we can perfectly well conceive, therefore, that the solar action would cut off the continuity of Jupiter's long-drawn clouds at the edge of his disc exposed to the sun, or slightly before the edge—just as the solar and lunar influence on the tides of the earth cut them off in the same way, making only this difference in the case of Jupiter, that in consequence of the greater mass and rapidity of motion they would be cut off more sharply and decisively in his case than they are in that of the earth.

Plate XX.

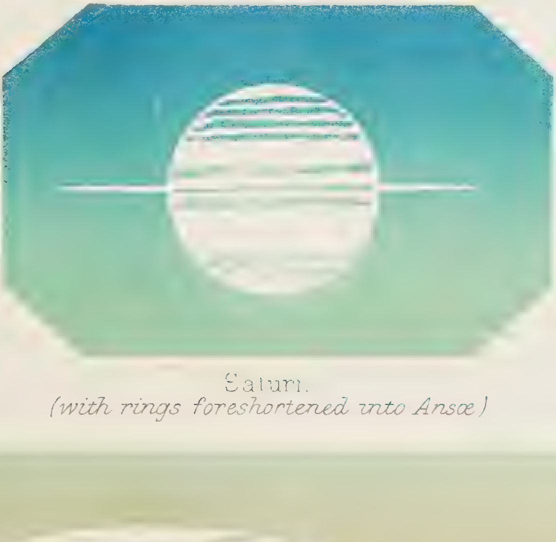
JUPITER and SATURN.



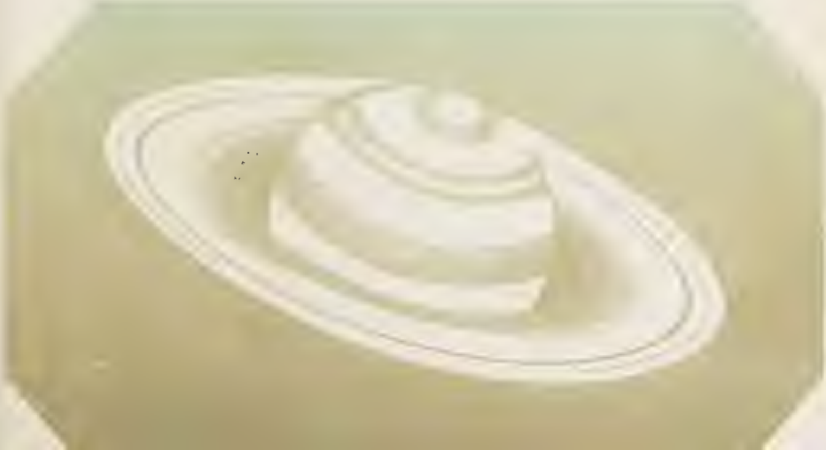
Jupiter (1863. Gorton)



Jupiter (1858 Lassel)



Saturn.
(with rings foreshortened into Ansœ)



SATURN

CHAPTER XXIV.

The elements of Saturn—The Rings—Their peculiarities—Supposed to be fluid—Special facts and possible explanations of their character and formation—Chemical considerations—The equatorial position of the Rings—Right of Chemistry to be taken into account in the explanation of them—Varying aspects of the Rings—The Atmosphere diffused round Saturn over his surface—Saturn's Satellites—Eclipses of the Satellites—Saturn known to the Ancients—Phenomena of the Rings to an observer on the spot.

In many particulars Saturn is an exceptional planet, distinct from all other members of the solar system, and from everything with which astronomy has made us elsewhere acquainted.

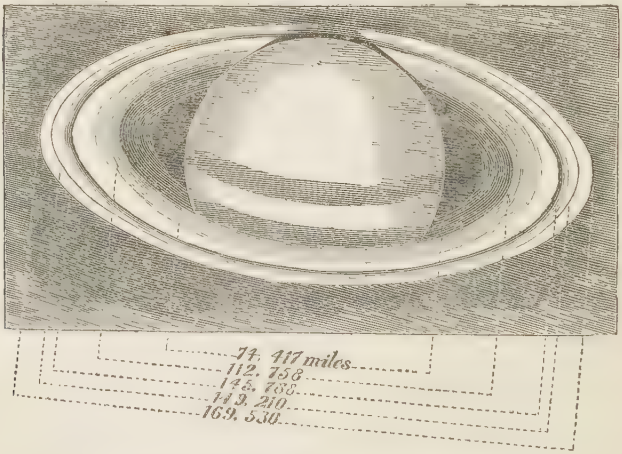
Its mean distance from the sun is	- 872,134	miles.
Its greatest distance - - -	- 921,105	,,
Its least distance - - -	- 823,164	,,
And its equatorial diameter is -	- 71,904	,,

Its polar compression is variously estimated from $\frac{1}{10\cdot34}$ to $\frac{1}{9\cdot02}$, and may be taken at one-tenth of its equatorial diameter.

It accomplishes its orbitual revolution round the sun in 29½ years (29·458y.), and its rotation on its axis in 10h. 29m. 17s.

The dimensions of Saturn, it will be thus seen, are not much less than those of Jupiter, and the rapidity of its rotation somewhat similar. Were Saturn placed in the position of the earth, it would hold the inhabitants on its surface thirty-six thousand miles nearer to the moon than the earth does, and the outer edge of the exterior ring of Saturn would extend to about one-third of the distance to the moon.

The ring, or rather rings, of Saturn—for there are three of them at least, and other divisions are being noticed—form the most remarkable characteristics of this planet, and have always been the subject of special interest. In the general appearance of its body, with its cloudy streaks and spots (the latter very rarely seen, however), Saturn differs very little from Jupiter—so fully dealt with in the preceding chapter as to render a recurrence to these peculiarities unnecessary here. To enable the reader to understand the ring system, and its dimensions, we must refer to the following diagram, in which we have exhibited, simultaneously with the aspect of the planet and its circumscribing annulæ, the dimensions and distances from point to point, according to the micrometric observations of W. Sturve.



In these measurements it will be seen that the dimensions of the third or dusky inner ring are not given. They do not, in fact, admit of very accurate observation; but the distance between the interior side of the inner bright ring and the ball sufficiently indicates the limits within which its dimensions are embraced. About the thickness of these rings there is some difference of conclusion. The difference, too, is very considerable, being from 250 miles according to Sir John Herschel, to only 40 miles according to G. P. Bond.

Various hypotheses have been discussed as to the formation and composition of these remarkable rings. The centrifugal-force theory of explanation has been more particularly insisted on, and in connection with the experiment of Plateau, before referred to in discussing Laplace's theory of the universe, looked upon as a special confirmation of that theory. The defective point in the analogy of Plateau's experiments we have already pointed out, and will not repeat here. There is no doubt the rings rotate or perform a wheel-like motion round the equatorial axis of the planet, according in direction, and probably also in velocity, with the direction of the planet's own rotation. If the velocity were greater or less than that of the planet, a curious question on the centrifugal-force theory would arise; but into this it is not possible to enter in the present state of observation as to the rotation of the rings. The rings of Saturn reflect light, therefore they cast a shadow; but as this shadow is not perfectly dark when cast upon the body of the planet—not so dark as the shadow cast by the body of the planet on the ring—and as the inner edge of the ring reveals only a dim shadow, of twilight intensity, it is concluded, not without reason, that the matter of the rings is fluid and translucent to some extent, though dense enough, from some cause, not to be perfectly transparent. In fact, they are brighter, and reflect more light than the planet, and the outer ring is brighter than the inner one, and more uniform in its brightness. The outer edge of the inner bright ring is generally the brightest part of the ring system—as if it intercepted most light—but it is believed to be of a variable brightness, as if not always of equal reflecting power. The inner, dusky, or thin ring is transparent, and Lassell at one time, during his first observations of it, described it as having the appearance of crape interposed between the planet and the observer. Mountains were supposed to exist on the rings at one time, from dark notches or projections observed on the line of their shadow as delineated on the body of Saturn; but this idea is considered untenable and incompatible with other phenomena, and Jacob ascribes the appearance rather to inequalities in the intensity of the shadow—an explanation much more in accordance with other features of the system. Attempts have been made to estimate the mass and thickness of the rings from their perturbing power upon the satellites; but the results are of doubtful accuracy, and the difference between Bond and Sir J. Herschel before mentioned may be found at length to arise from a varying thickness at various times, or from a tendency of the rings to oscillate to a small extent; as it has been stated by some observers that they are not exactly in the same plane, a conclusion which has been denied by others.

If the general conclusions above stated be fully confirmed by further observation, they involve a very curious result, which may, perhaps, give a totally different character to the formation of the rings from that which is at present sought to be assigned. The rings are said to be fluid, and their matter we may consider to be consequently *lighter* than the solid matter of the planet. Let us suppose that the three external gases of our atmosphere and ocean were diminished in unequal proportions, so that only a very small proportion of oxygen and a very small proportion of nitrogen, not greater than that of oxygen, remained, while the proportion of hydrogen was also smaller but in greater proportion than the other two. What would be the result? The hydrogen liberated from its chemical affinity for oxygen, under the present large and dominant proportions of the latter, would rise to its true level from the earth with only enough of oxygen in its lower stratum to make a light vapour. The oxygen and nitrogen would float intermedially below, but if the proportion of nitrogen and oxygen were much less than it is, the compound of oxygen and nitrogen formed would be too light to descend to the surface of the earth. We should thus have three strata of different compound character floating at the proper altitude of their specific gravities above, but not in contact with the earth; and so little of these as not to be capable of extension over the whole surface of the earth's sphere like a concave but distant veil, but only enough of them to form a belt round it. Round what part of it might we expect such a belt to move or arrange itself? We presume there can be little doubt that it would range itself round the belt of the equator under the tidal or attractive power of the moon and the sun, and that it would be drawn out by their attraction into a more or less thin plane, just as the water on the earth's surface would be drawn round the equatorial region in a similar ring, were there not enough of it for greater diffusion, and were its weight, at the same time, so much reduced that the solar and lunar attraction was about nearly equal to its own gravitation. Of course such an explanation of the rings of Saturn, and the mode of their formation, can only be suggested, however certain it may be that such would be the effect on the arrangement of external gases in the circumstances supposed.

Saturn is so remote from the sun, that, like Jupiter, its atmosphere and ocean cannot, under its proportion of solar temperature or superficial heat, be of the same chemical composition with those of the earth, otherwise its ocean could not be in a fluid state; and hence it is not possible to suppose the matter of Saturn's rings to be gases of the same nature with those of the earth. Their fluidity may thus consist of elements of a chemical character, which we have no analogy to, save that they are subject to the same laws of gravitation and chemical affinity which prevail in the chemistry of the world. Many considerations which become of great importance when chemistry is correlated with astronomy on this subject, conspire to show that it is not mere centrifugal force that can have to do with the present position and form of these Saturnian rings. It is impossible to believe, in the first place, that the force of the planet's present rotation on its axis can have thrown any of its matter outward from it into the position of these rings, without giving at the same time the whole remaining portion of its volume a much more flattened shape than it presents. The centrifugal force which could throw matter into the form of these rings must have been of a very different intensity from that which has modified the sphericity of Saturn's own body in so comparatively trifling a degree. Then it is manifest that the matter of the rings still retains a concentric attraction for the mass of Saturn; but if the rings be fluid, there must be some portions of the fluid heavier than others; for the interior and exterior rings show a marked distance between their nearest and furthest surfaces from the planet—according to Sturve's measurement, amounting to more than twenty-six thousand miles—and we cannot believe that the matter which is floating at eighteen thousand miles above the surface of the planet, as the inner surface of the interior bright ring does, can be so light as the matter which is floating at forty-four thousand miles above the surface of the planet. There must be some chemical peculiarity, some distinctive difference of specific gravity, which makes the one portion of the matter float so much lower than the other. Of course those fond of arguing centrifugal force too far will tell us that this is accounted for by the force acting in proportion to the distance from the axis of rotation, and maintaining the matter there; but this explanation will hardly meet the case, for we know that centrifugal force at the equator of the earth will not prevent a heavier body than water sinking to the bottom of the equatorial ocean bed, or a lighter body than water from rising to its surface, or a difference of temperature in the water from diffusing itself and establishing equilibrium of temperature. And there can be little doubt that the lower part of Saturn's rings must sometimes be the higher in temperature, and the lighter, from the effect of Saturn's own reflection upon them, combined with direct sun-light, being greater than it is upon remoter portions of the rings; just as it is with our own atmosphere, in which we find that the highest portions are the colder, and the lower portions—heated by the combined light of the sun and the earth's reflection—the warmer and lighter; which causes the stratum of warm air from the earth's surface to ascend and seek its level, until it has lost its excess of caloric by radiation. The different altitudes then of the rings above the surface of Saturn must be maintained by something more than centrifugal force, and must be the result of modified specific gravity, just as the different altitudes at which vapours, etc., float in our own atmosphere are found to be so. If this be the case, and analogy insists for it, it is not so difficult to understand the vertical extension of the ring and its arrangement of itself in the plane of the equator, which, in addition to the solar attraction which would draw and retain it there, is also *the plane of the planet's greatest attraction* upon matter exterior to itself.

It will not do, in a question of this kind, for astronomy to throw chemistry overboard because it does not in all respects pay a flattering homage to preconceived theories or pet speculations. Since alchymy gave way to the real work of analysis, no science is less tainted with extravagance, less free from mere hypothesis, than chemistry. It is as a science at once pre-eminently accurate and unpretentious.

In no instance does chemistry come in with more conspicuous propriety to the rescue of scientific truth than in this question of the structure and composition of Saturn's rings. If these diaphanous and fluid rings were of homogeneous composition such as water, chemistry authoritatively tells us that it would not stand out, or up in ridges, like these projecting girdles of Saturn, but would find its level as water does, by a distribution equally all round the planet, with one surface level such as our sea has; for even in the illustration we made use of just now, as to an equatorial belt of sea round the terrestrial equator, we had to suppose a decrease of weight in the water in deference to chemical law sufficient to enable the attractive influence of the moon and sun to counteract the tendency of the water to find its level by a general dispersion. But in the case of Saturn's rings the whole question is much stronger; for we find in that case the tendency of the matter to seek its own level so completely overcome by the influence acting on it, whatever that may be, as to leave it free to obey another and more powerful law of some kind than any law of gravitation it can have, unless we are to assume, as already indicated, that the gravitation of its several altitudes is unequal, so that its several elements are at their respective and proper altitudes already, and that the proper degree of distribution has thereby been attained. These are facts and principles of chemistry, so well established by all our knowledge and experience of the earth's operations, that there is no denying or evading them in a question where analogy is the only guidance we have to investigation; and we have, unfortunately, no other guide here. Let it not for a moment be supposed that by all this we deny the existence of centrifugal force, for we as fully admit it and its importance where and to the extent to which it really exists, as any one; but Newton *understood* centrifugal force, and knew something of its limits. It has been singularly misconceived and misapplied since his time.

Such then is something like what we know and what we do not know of Saturn's rings, and it is not plunging the question much deeper into controversy or dubiety than before to invest it with the new difficulties and probabilities we have just propounded. The subject is of remarkable interest, and it is not doing much harm to throw upon it the broadest light which analogy can afford. The eccentricity of the rings is another question of importance; but as yet sufficient care has not been taken to ascertain that their aphelion distance from Saturn is always toward the sun.

At times the rings of Saturn are seen so angularly situated to us, that the space between the planet and the rings, and between the two outer rings, can be distinctly seen through. In this position the planet has much the appearance of an oval, to a beholder with feeble powers of observation, such as unfortunately Galileo had to contend against when he first saw this magnificent planet; for to him the rings and the ball appeared but as one object. This error is corrected by observing at other times that the rings are so fore-shortened to our view as to present the appearance of a straight rod passing through the equatorial diameter of the planet, and forming by its position on either side handles to lift it by, whence the projecting points in this position have been called *ansæ* (handles).

It will be seen by what has been before mentioned—but lest the general reader should fail to draw the conclusion for himself, we direct his attention specially to it—that Saturn has an atmosphere diffused all round his body, like our own in its envelopment of his spherical mass, whatever may be its difference in chemical composition; and that the ring system of this remarkable planet is above and exterior to this all-surrounding atmosphere; so that the ring system must be much lighter in its specific gravity than the atmosphere in contact with and spread over the body of the planet below it. It is thus evident that if the ring system be of a fluid character, and its semi-transparency places that almost beyond a doubt, it cannot owe its elevation and peculiar position to a centrifugal force which has been utterly powerless to disturb the natural atmosphere, if we may be so permitted to call it, of the planet, or affect its normal concentric diffusion and arrangement round the surface of the sphere.

This planet, in addition to the magnificent phenomena of its rings, is accompanied by no less than eight satellites, and this imperial train of attendants is ranged round the primary with a great amount of variety; the largest being by no means the nearest, nor the smallest the most distant, as will be seen from the following statement of the diameters and distances:—

	Diameter. Miles.	Revolution in orbit.	Mean distance from Saturn in Miles.
1. Mimas	1,000	22h. 37½m.	120,000
2. Enceladus	not known.	1d. 8h. 53m.	155,000
3. Tethys	560	1d. 21h. 18½m.	191,000
4. Dione	560	2d. 17h. 41m.	245,000
5. Rhea	1,200	4d. 12h. 25m.	343,000
6. Titan	3,300	15d. 22h. 41½m.	796,000
7. Hyperion	not known.	21d. 7h. 7¾m.	1,000,000
8. Iapetus	1,800	79d. 7h. 51⅔m.	2,000,000

The sixth of these satellites, Titan, is that best known, as its dimensions have rendered it more conspicuous and better fitted for minute observation. It will be seen that five, if not seven, of the satellites of Saturn are considerably smaller in diameter than the moon, and consequently much smaller in actual volume. The first three of the above satellites are nearer to the centre of Saturn than the moon to the centre of the earth; the fourth is a little more distant, and the remainder increase considerably in their distance. The distances, however, are so irregular and unsymmetrical, that we may here say with safety, if the law of distances given by Bode, and by means of which, in some measure, the planetoids were discovered, be anything with regard to planets, it is absolutely nothing with regard to satellites. From the surface of Saturn the satellites are not so far as the above distances; which are from his centre—the satellite Mimas being only about eighty-three thousand miles above the surface of the planet, or about one-fourth part of the distance of the moon from the earth. It is consequently only about thirty-six thousand miles above the outer edge of Saturn's ring system, or less than half the diameter of the planet from the ring. The largest of Saturn's satellites was the first to be discovered. The two first in order were discovered by Sir W. Herschel, in 1789; the third and fourth by Cassini, in 1684; the fifth and eighth by Cassini, in 1672 and 1671 respectively; the sixth, third, fourth, and fifth, being thus the first four discovered; the seventh was discovered in 1848, by Bond and Lassell; and the sixth and largest, and most easily seen, in 1655, by Huyghens.

Iapetus, the eighth satellite, varies very much in its luminosity—possibly from revolutions on its axis, in the same time as its revolution round Saturn, like the moon in its revolution round the earth, and from spots unequally distributed on its surface, and depending, like the moon, on the mode in which shadow is projected from its elevations or mountains. This appears a highly probable explanation, as Sir William Herschel found that the minimum of its light corresponded with a certain position in the eastern portion of its orbit. And Cassini drew this conclusion accordingly.

The eclipses of the satellites of Saturn, as well as their transits, form a series of interesting phenomena, like those mentioned in the preceding chapter with reference to Jupiter, and in Saturn's case the interest and beauty of the phenomena are greatly enhanced by the presence of the rings. It will be seen, from the above table of figures, that the satellites perform their orbital revolutions with great rapidity—all of them in less time than the moon, except Iapetus, whose immense distance from its primary, more than eight times that of the moon from the earth, may well account for its taking nearly three times longer than the moon to traverse its orbit.

Saturn is the last of the old planets of astronomical science. When and by whom first discovered is not known. The Babylonians were well acquainted with him; as Chaldean observations of a very early date exist. Modern science has, however, greatly increased our knowledge of this planet and his system. A great deal of imagination could be expended on the appearance, to an observer on the spot, of Saturn and his associated phenomena. To an observer from the region of his poles his rings would be below the horizon, and altogether unseen, so that an inhabitant at that point—a Saturnian Esquimaux, shall we call him?—might live and die without knowing that such things existed as the rings of the system, and possibly also without ever seeing the five nearest of the eight satellites. An observer near to the rings on one or other side, would find on looking up that instead of a hemisphere to look at, as we have on the surface of our earth, he had only half a hemisphere; the other half being cut off from his view by the dead wall of the precipitous ring, and that all the view he could obtain of the other portion of the hemisphere would be through the loop between the body of the planet and the interior ring. At other points, such as an angle of 45° from the pole, he would see the ring projecting outward like a great terrace, sometimes in full sunshine, sometimes in dim or twilight-like shadows before him, as if they formed a continuous portion of the planet without any interval between the body of Saturn and them, and standing up as a crescent-like termination to his landscape in that direction, or a sheer wall, towering high and vast from one side of the field of view to the other, far above all his mountain ranges. And the reader can easily imagine or construe these positions by a toy model of Saturn and his rings, made with a boy's marble, inserted eccentrically in a piece of cardboard cut and shaded to represent the rings, and then placing it in all possible positions to the eye, so that we need not multiply instances of this kind, which are after all very much of the nature of wax-doll astronomy.

URANUS:

CHAPTER XXV.

The elements of Uranus—The Satellites of Uranus—Their densities and periods of revolution—Their retrograde direction—Peculiarities of the Seasons of Uranus—The difficulties attending the discovery of this Planet, and of distinguishing it from a Fixed Star at the period of astronomical history when the discovery was made.

The planet Uranus is a very modern addition to our astronomical knowledge. It is yet only an octogenarian to the human observer, though, doubtless, it is quite as ancient to the sun as any other member of his magnificent retinue. First seen and announced by Sir William Herschel in the early part of 1781, it appeared long doubtful to that eminent astronomer whether it was not a comet only. All Europe was soon engaged in the observation of it, and, at length, Lassell was enabled to determine its orbit, and decide that it was a new planet. Then followed a long discussion about its name, which has at last happily ended without bloodshed in a general acceptance of the name Uranus, suggested by Professor Bode—the alternative names Georgium, Sidus, and Herschel being obsolete.

The mean distance of Uranus from the Sun is - - - -	1,753,851,050 miles.
The extreme distance- - -	1,835,700,854 miles.
The least distance - - -	1,672,001,276 miles.

Its diameter is about 33,000 miles, or four times that of the earth, and its polar compression has been stated at one-tenth of that diameter, though this requires confirmation.

The revolution of Uranus in its orbit is accomplished in about eighty-four years, and its rotation on its axis in about nine and a half hours.

Uranus is attended by eight satellites, though Lassell has recently denied this, and stated that there are only four—the first, second, fourth, and sixth of the following table, the only ones which have yet received names. In presence of Lassell's assertion the other four may, therefore, in the meantime be considered doubtful, though eminent astronomers have accepted the evidence in favour of eight.

[The rotation of Uranus on its axis is uncertain, as there are no spots or belts upon it which are yet capable of detection. This uniform brightness of its disc, however, may arise entirely from its remoteness, and the feebleness of its illumination preventing such a distinction between the brighter and darker points of it being visible at our distance from it.]

The satellites of Uranus are as follows:—

	Mean distance from Uranus in miles.		Revolution in orbit, sidereal period.
1. Ariel - - -	122,849	Diameters still unknown.	2d. 12h. 28m.
2. Umbriel - -	171,229		4d. 3h. 27m.
3. - - -	216,637		5d. 21h. 25m.
4. Titania - -	230,869		8d. 16h. 55m.
5. - - -	327,763		10d. 23h. 3m.
6. Oberon - -	375,648		13d. 11h. 6m.
7. - - -	751 461		38d. 1h. 48m.
8. - - -	1,502,575		107d. 16h. 39m.

Whether there be eight or only four of the satellites, there is no dubiety about one fact of a very remarkable character; viz., that all the satellites of Uranus have a retrograde motion, and move in their orbits in a direction the reverse of every other planetary body or satellite of the solar system, with the exception of the satellite of Neptune. In this respect they appear to give the most unqualified contradiction to Laplace's theory of the development of the sidereal system before referred to, as their motions are in the opposite direction to the centrifugal force by which they are assumed on that theory to have been set in motion, so far as we can judge from present observation or knowledge.

The axis of Uranus being in the plane of its orbit, its tropics are transverse to its equator, and run round its body from north to south, and south to north, speaking with reference to its own poles, instead of from east to west and west to east, as they would do were they the same as the tropics of the earth. In consequence of this peculiarity, when the sun is perpendicular to its equator, both its poles are under light; and when the sun is perpendicular to either of its poles, the other pole and the whole hemisphere on the same side with it, beyond the equator, are in darkness and winter, and this winter must continue for twenty-one years each time it occurs within its polar circle, with an alternating summer of equal duration. From this peculiarity of the polar axis of Uranus, such an appearance as that of the cloud streaks or bands of Jupiter and Saturn could not occur to the same degree, nor precisely in the same way, even were there atmosphere and ocean on the surface of the planet, a fact which has not yet been ascertained. Indeed, information of a reliable nature about Uranus is still very meagre, from difficulties of observation.

It may be interesting, however, to note that Uranus had frequently been observed before Sir William Herschel's discovery of it, and always noted down as a fixed star; and Arago mentions that if Herschel had been eleven days earlier in his observations he would have found it at one of its stationary points, and repeated the same error, as the telescopic power with which he first observed it was not great enough to reveal its disc; and it was not until tempted to further observation of it by its motion that he applied higher telescopic powers, and found the distinction between it and the fixed stars. This singular fact shows by what a narrow set of circumstances its discovery was made.

NEPTUNE.

CHAPTER XXVI.

Neptune—The mathematical triumph achieved by its discovery—The combined merits of the discoverers—The elements of Neptune—The Satellite of this Planet—Its retrograde motion in its orbit—The positions of the Planet indicated by the two calculators, and its position when found—General remarks and *résumé*—The universe—Relative importance of the material and the metaphysical.

ADAMS—LE VERRIER! LE VERRIER—ADAMS! How shall we jextapose these distinguished names to satisfy all the demands of jealous partizanship? Twins in the honour of having achieved the most brilliant mathematical and astronomical triumph on record, they seem to have been born to this honour somewhat like Esau and Jacob, the younger having laid hold of the elder's heel, and having in some degree forestalled him in the one only birthright.

In 1843 Mr. Adams, of Cambridge, began his investigation of the orbitual perturbations of the planet Uranus, the subject of the preceding chapter; the regularity of its orbitual motion being subject to disturbance from some unknown cause. The specific object of the investigations was to fix the position of the influence from which these perturbations proceeded, and Mr. Adams completed his calculations, and communicated his results to the British Astronomer Royal in October, 1845, which clearly indicated to him where to look for and find a new planet. He also in the month of September previous (1845) made the same communication to

Professor Challis, of his own university. On the 4th and 12th of August, 1846, Professor Challis found the planet without being able to recognize it, from not comparing his observations, under pressure of other occupations and some impression that further research was involved, for which he would require to have more time at command. In the meanwhile, on the 25th of September, 1846, Dr. Galle, assistant to Professor Encke, of Berlin, discovered the new planet, and at once published the discovery. Dr. Galle's discovery, however, was not made on the basis of Mr. Adams' calculations, of which he knew nothing, but on the independent calculations of M. Le Verrier, who knew nothing of Mr. Adams' investigations, but made his own at the instigation of M. Arago, and communicated them to the French Institute on the 10th of November, 1845, and 1st of June, 31st of August, and 5th of October, 1846, and at once published them.

The heliocentric position in which the new planet Neptune was thus found by Dr. Galle, was	326°	52′
By the computation of Le Verrier it should have been at	326°	0′
And by that of Adams at	329°	19′

It will thus be seen that a trifling degree of closer approximation to the true position was made by Le Verrier, but not of the smallest moment, or such as to justify the slightest discredit of the accuracy of Mr. Adams, whose calculations would have just as certainly led to Galle's detection of the planet, had they been in his hands, as those of Le Verrier did. Thus by a slip on the part of Professor Challis, who had the game actually in his hands, the laurel crown has been rent into two wreaths between Adams and Le Verrier; and even in that state they may both be well satisfied; for their honours are still sufficiently high and unapproached. Between Adams and Le Verrier alone, the question of time is decisively in favour of Adams, and, had Professor Challis and the Astronomer Royal been equally alert, M. Le Verrier after all his trouble would have been a discoverer after the fact. Would this have been quite a fair reward for such a distinguished and meritorious labour? for there cannot be a doubt of the equality of merit between the two. Or may we not be rather satisfied that Le Verrier's labour did not go without its recompence? Of Galle's pre-eminent right to the honours of the actual detection and proclamation of the planet—the undivided Eureka! of the triumph—no question exists; and if Professor Challis and the Astronomer Royal felt chagrined that they missed this distinction, we fear that England must be content to say to them in the language of its great bard:

> "The tears were conceived in an onion that should water that sorrow."

The statistics of Neptune are still very limited:

Its mean distance from the sun is . 2,746,271,232 miles.
Its greatest distance . . . 2,770,217,344 ,,
Its least distance . . . . 2,722,325,129 ,,
Its diameter is greater than Uranus, being 36,620 ,,
(four and a half times that of the earth).

Its orbitual velocity is about 12,000 miles per hour.

Its orbitual revolution is accomplished in about 165 years.

Its rotation on its axis, as well as its polar compression, are as yet unknown, and will possibly continue to be so.

Its density is about one-sixth part that of the earth.

Neptune is accompanied by one satellite, the existence of which has been fully confirmed, and another has been suspected both by Lassell, the discoverer of the first, and by Bond. The satellite known has a mean distance of 220,000 miles from Neptune, and performs its orbitual revolution round the planet in five days, twenty-one hours, eight minutes; so that, if Neptune's months be calculated by this—

the circuit of its moon—it must have upwards of ten thousand months in its year, or more months than we have hours in our year! Like the satellites of Uranus, as already mentioned in treating of the Uranian system, the motion of this satellite is retrograde.

RÉSUMÉ.

Such, then, are some of the more prominent features and rationalia of that creation within a creation—that small solar system within the great star systems and magnificent nebulæ of which this petty atom of a world of ours forms, however philosophy may argue it otherwise, *to us*, unquestionably, the more important part—the arena of our action—the sphere of our duty and responsibility—the opportunity of our irrevocable moral decision, and its infinite and eternal consequences. In the great science we have, with deeply conscious inadequacy, been endeavouring to explain, we know only, beyond our own terrestrial confine, that there is *Matter*, interminably scattered through all penetrable space, poised, and controlled, and orderly arranged in its combinations and forces by an universally harmonious, irresistible, and omnipresent Power. But within our own immediate confine—petty as it physically must be conceded to appear—we are conscious that there is something higher, more momentous, and vastly more important than Matter; that there are life, and feeling, and thought, which are not of its attributes; that there are intellectual distinctions, of which it has no perception; that there are truth and falsehood, virtue and vice, right and wrong, which do not come within the range of *material* cognizance, and, in their ethical qualities, are not operations or effects of Matter. Stars may shine out with brief brilliancy, like "diamonds on the ebon cope," and disappear ; systems may be extinguished ; physical annihilation and reproduction may ensue; but of what importance are such events and their consequences on mere inanimate matter, though all that astronomy has made known to us of it were involved in the change or the destruction ? The universe suffers not from these things no more than from the extinction of a marsh meteor, or the breaking of a stone. Does the monarch, with a pyramid for his tomb, lie the more potent in death, because of his cumbrous mausoleum, than the whitening skeleton of the unburied outcast lost to humanity amid the desert sands ? Is not vitality itself the more important of Creation's works, and chiefest of them all when endowed with feeling, moral obligation, and intelligence ? And would our vitality be one whit more important though it were clad in the whole matter of the universe, than it is in its fragile temple of limited terrestrial clay ? What would added matter do, but further clog and encumber the soul ? What qualities, then, higher than those possessed by the rudest peasant of our race, hovelled in the humblest hut, can Creation conceivably confer on the mightiest of her works, or the brightest of her shining spheres ? what nobler powers than those with which self-degrading man moves in this world, the unconsciously incarnate image of the Lord of all ? Where can the same intelligent impression of a Divine Originator be pointed to in the wide heavens of material astronomy above, or in the globe of complex chemistry beneath ? Why, then, will philosophy perversely dominate the truly little over the truly great ? In the scheme of an *intelligent* universe, there is more importance in the cry of a feeble child just dawning into being, or the shiver of a ragged beggar wincing in the untempered wind, than in the creation of a tenantless moon, or the arrangements of whole systems of matter. These heavens may declare the glory of God, and interminably demonstrate His handiwork in whatever direction we turn to explore; but His intelligence is *on*, not *in* them—they are unconscious witnesses after all; they cannot join the Psalmist's appeal, and worship their Lord with understanding. But woe to the agonized sinner, drowning in the ocean of time, if his voice cannot transcend theirs, and supremely passing them all before the Great White Throne, penetrate and melt the very heart of his God!

This world we do know to be inhabited—fraught with a charge of the most vital and imminent moral importance. Other spheres or systems may or may not be so—that is uncertain—but certain it is that their moral interest cannot exceed ours in deeply involving consequence. It is no wild speculation of philosophy which, from the primary capacity to perceive the difference between right and wrong, common to all men—and only displaced from its importance by mere ratiocination in the positivist and pantheistic mind—impels the untutored Indian to exclude the bad man from the happy hunting fields of a bright hereafter, with as clear a consciousness of rectitude as that which, to the Christian, excludes him from the heaven of revelation. If, therefore, our sympathies are right, the question whether those other spheres be inhabited is of importance, or not, just in proportion as we believe or disbelieve in that great tribunal of final appeal against suffering, without which life here or elsewhere, present or hereafter, is only liable to become a terribly unmitigated and hopeless calamity. Suffering, we know, does exist. We require no philosophy to teach us that which our own wincing experience has demonstrated with poignant certainty to each—that "all creation travaileth in pain." If the pantheist or positivist's creed be true, that matter is self-existent and eternal, then—as inevitably as parity of reason can make it—all that is is self-existent and eternal, and *suffering is,* and, as such—*self-existent is, and is eternal.* That is an inseparable corollary of such a creed. We who believe in a divine supremacy over all, believe along with it nothing so horrible as this. We believe that Wisdom immaculate, and Goodness and Purity—untainted by an act, unsullied by a thought, of wrong—reign on the great Everlasting Throne, armed with Omnipotent and all-protecting Power. We do not believe that in the exercise of that Power even vengeance itself ever offends against justice—ever becomes an immorality or a transgression against spotless righteousness. We only learn from the positivist and pantheist the possibility of a hell worse than the fiercest passions of unbridled rage ever conceived against a hated object; an eternity of suffering which no hatred provokes or frames—no retribution justifies—no moral requirement sanctions; a perpetuity of evil, which may be the lot of the innocent, of the good, and of the gentle, just as likely as of *direst malignity and guilt;* because in their creeds it is an evil, to which no righteousness prescribes limits, and over which no controlling intelligence presides. This is an essence of the positivist and pantheist's argument; and, therefore, realities more fearful, and despair more perdurately deep, than irreligion ever urged against faith—than alarmed conscience ever whispered of an offended God—are *certain* if the pantheist's creed be true. Their creed does not uncreate existing and known affliction—does not make lamentation and weeping, and gnawing sickness and pallid death less certain of or around us, than they are in the fullest sympathetic recognition of Christian compassion, and intelligent and all-consoling mercy. Their creed only serves to render these terrible experiences less intelligible—more hopeless, causeless, unaccountable, and irretrievable, than the Christian can believe them to be. *They* dethrone redress, and deliberately crown despair. They arrogantly deny a guardian Deity, before whom we are not utterly consumed only because His compassions fail not, to proclaim their dumb insensate idol, *Nature*, riding her blind Juggernaut car, in His stead. But it is the old phenomenon of human degradation, after all, under the characteristics of an enlightened (?) age!—Man departing from his Maker ever falls down in abject idolatry, as the alternative, before dead matter, either in the mass or the particular—either, as the pantheist, acknowledging the supremacy of the whole lump, or, as the dusky savage, contented with a part!—in each case the miserable worshippers, mentally as well as morally prolate, equally ascribing their afflictions or their hopes to that which is speechless and unintelligent. *They never show themselves capable of conceiving a higher or a better God.* Their *superior* worship is down plump, and at once to the supremacy of the stock or the stone! As if the grave could spare us if we prayed to it, or the spirit of Nature could be evoked by apostrophising it in an alembic! How can it be but that such beings should be deceived in life and comfortless in death? How infinitely superior must it be when the intelligent and candid soul, distrustful of this shallow faith in that which cannot see, nor hear, nor feel, looks upward hopeful to the Source of all—when the weary heart of our humanity is able to rest *in the full assurance* of a faithful and gracious Creator!—can appeal to its desponding fellow-sufferer in words of comfort like these: "Lift up your eyes on high, and behold who hath created these things, that bringeth out their host by number: He calleth them all by names by the greatness of His might, for that He is strong in power; not one faileth. Why *then* sayest thou, My way is hid from the Lord, and my judgment is passed over from my God?"*

When will the wisdom of the world learn that truth does not change itself to accommodate controversy, and is not displaced by the humiliating infliction against it of a triumphantly adverse argument? Mankind take, with singular ease, to processes of self-deception, and, without using the pains to make sure that they *do* well, will say, without even an ingenuous blush, that if they only *mean* well, it is all right enough. Did they ever know of a well-meant administration of poison sparing its victim—of the fatal venom changing its nature in deference to the *intention?* Why, then, should we presume to expect that moral truth will change, when physical truth obdurately and obviously will not? What instance or authority can we cite to indorse the fallacy of our silly thought? So may we be assured that He who made these heavens and all their host will persistently maintain His authority in righteousness and unwavering truth, and effectuate His potent purpose, indifferent to all the arguments, and irrespective of all the self-deceptions, of the creatures of a day—the ephemera of an ephemeral world—who dare to judge of the heaven of heavens as arrogantly as if they knew and beheld it, and presume to dictate to the whole unfathomable universe around them whether it shall or shall not—*have a* God!!

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* Isaiah xl. 26, 27.

PART III.

SPECTRUM ANALYSIS.

CHAPTER XXVII.

Discovery by Sir Isaac Newton of the prismatic spectrum—Theories of Newton, Brewster, and Helmholtz—Wollaston's and Fraunhofer's discoveries—Sir J. Herschel and Mr. Fox Talbot's discoveries—Professor Snow's discovery of the sodium reaction—Bunsen's discovery of cœsium and rubidium—Mr. Crooks' discovery of thallium—Professors Reich and Richter's discovery of indium—Sir C. Wheatstone's previous discovery of distinctive metallic lines—Difference under certain circumstances between the spectra of compounds and their elementary components.

So many references have been made to spectrum analysis in the course of the preceding chapters, and so much interest attaches to the subject, that the general reader may expect from us something more in explanation of it, and its connection with sidereal chemistry, than the scattered remarks parenthetically introduced through the preceding pages in the course of other subjects of discussion.

To Sir Isaac Newton we owe the first discovery that white light is capable of being prismatically developed into the various rainbow tints exhibited by the spectrum. This discovery he made by admitting a small amount of solar light into his darkened room through a round hole in the window shutter, and interposing a prism between it and the opposite wall, when, instead of exhibiting a round white ray corresponding with the size of the aperture by which it was admitted, it underwent refraction, and became spread out into a beautifully coloured band. He also found that these colours, when recombined by another prism, became a ray of white light again. This was both analytical and synthetical proof that white light is composed, to all appearance, of the colours of the spectrum. We have since found that, though these colours were originally noted as seven,—viz., violet, indigo, blue, green, yellow, orange, and red,—the three colours, blue yellow, and red, are sufficient to produce all the other tints by mixture, and that, therefore, the other tints are compounds, while these three are pure, primary, or elementary colours. Yet it must not be overlooked, that while green may be produced by the admixture of blue and yellow, the prism fails to analyze green light into yellow and blue by further refraction. The theory of Sir David Brewster on this subject was that the compound colours of the spectrum were produced by the overlapping of the edges of the primary colours at their points of contact; but Helmholtz has shown that the compound colours cannot be analyzed, and he hence concludes that all the seven tints are each monochromatic. This conclusion, however, must be regarded with distrust, as rather exhibiting the existing limits and defective power of spectrum analysis in this direction, than disproving the theory of compound colours; for it is far too well established by experiment in other directions that we can produce these compound or intermediate tints from the mixture of the three primaries, and separate them into their components again, to admit of our doubting them to be compounds, merely because spectrum analysis cannot decompose them. Nay, in this respect, spectrum experiments prove synthetically what they fail to accomplish analytically; for why should violet and greenish yellow produce white light, and white light in return produce all the colours of the spectrum, if it be not that the greenish yellow and the violet contain in the first instance all these seven tints, though we cannot produce them from the violet and greenish yellow directly, but only indirectly by synthetical combination first and by analysis afterwards?

The dark lines of the solar spectrum were first discovered by Dr. Wollaston, and it is their discovery which forms the basis of the new science which has achieved such notable triumphs in reference to terrestrial chemistry, and enabled Professor Bunsen, in 1860, to discover the two new alkaline metallic elements, cœsium and rubidium ; Mr. Crooks, about the same time, to make his celebrated discovery of the metal thallium ; and Professors Reich and Richter, in 1864, to discover the metal indium.

Dr. Wollaston's discovery arose from his using, instead of the round hole in the shutter, a delicate vertical slit, and applying his prism to the light passing through it in a position which placed the edge of the angle of refraction parallel to the line of the slit. This revealed what the round hole could not and does not show—that the spectrum is interrupted at various points in its continuity by a very great number of permanent dark lines. About twelve years after the announcement of Wollaston's discovery, the German optician Fraunhofer, who had devoted much attention to the subject, gave publicity to a map or diagram containing no less than 576 of these permanent lines, and at once assigned the cause of them to something external to the atmosphere of our world. He found that the lines were universally present in analyzed sunlight, whether that light were direct or reflected from the moon or the planets ; and he also observed that the spectra of the fixed stars differed in the lines they revealed from those of the sun.

From subsequent investigations by Sir John Herschel, in 1822, of the spectra given by coloured flames of boracic acid, nitrate of copper, and the chlorides of strontium, potassium, and copper—and subsequently from the colours which he found to be given by salts of lime, strontia, lithia, copper, baryta, and iron—he was enabled to come to the conclusion announced by him in his article on light in the *Encyclopædia Metropoli-*

tana for 1827,—that the colours given to flame by different chemical bases formed a neat way of detecting minute quantities of them. Mr. Fox Talbot, in 1826, announced that the spectrum of red fire used in theatres showed many light lines or maxima of light, and mentioned many of them, more especially the red potassium line which he ascribed to nitre (nitrate of potassa), not *then* perceiving that it was due entirely to the potassium element in the nitre. He also referred to the blue line now found to be given by strontium, and the yellow line which he considered to be caused by the combustion of sulphur, but which is now definitely ascertained to be the well-known sodium line; these observations were of the very greatest importance, imperfect though the detection of their cause may now appear, and they give Mr. Talbot a high place among the distinguished promoters of this new branch of science. But it is more especially to the soundness and forethought of his conclusion then come to that special praise is due; for he says, founding upon his previous remarks and his ascription of the cause of these lines to different chemical substances, that "a glance at the prismatic spectrum of a flame might show it to contain *substances* which it would otherwise require a laborious chemical *analysis* to detect;" for this is just precisely what subsequent observation of the prismatic spectra has triumphantly established. His subsequent observations of the spectra of lithia and strontia, announced in 1834, contributed still further to the development of the method, and demonstrated the power of optical analysis to "distinguish the minutest portions of these two substances from each other with as much certainty, if not more, than any known method."

Sir John Herschel, Sir David Brewster, and Mr. Talbot, had also been engaged, from time to time prior to this, in the investigation of the monochromatic flames given by the combustion of various bodies, and especially the yellow light, now known to be given by sodium in the minutest quantity, but which appears from that circumstance to have rather perplexed and misled them, as they had no suspicion of its subtlety and ubiquity, but came to the conclusion that they had the yellow light under circumstances in which they thought no sodium was present. Professor W. A. Miller's experiments at a considerably more recent date (1845), on the spectra of the flames of the alkaline metals, kept attention to the subject alive, and showed a number of peculiarities tempting to further investigation, though his experiments and diagrams (the first published of the spectra of flames) were in some essential particulars defective. But Professor Snow, in 1857, at length found the identity of the hitherto perplexing yellow sodium line and the extreme sensitiveness of the sodium reaction. His discovery was incidental to an investigation of the spectra given by the flames of different hydro-carbons, and may be said to have also fixed the carbon and hydrogen lines, since he reports that an "absolute identity exists between the spectra of dissimilar carbo-hydrogen compounds."

In 1860, Bunsen reduced the long suspected powers of the new method of investigation, as already intimated by Herschel and Talbot, to the test of demonstration in a new direction, by his great discovery of the two new metals, cœsium and rubidium. In that year he observed that certain alkalies obtained by evaporation from the mineral water of Dürkeim gave, when examined by the spectroscope, some bright lines which he had not previously seen; and this discovery so stimulated him to further investigation, that he at once proceeded to evaporate forty-four tons of the water for the purpose of finding the new elements it contained, and which, from the colour of their lines in the spectrum, he named cœsium (greyish blue), and rubidium (deep red). The delicacy of the task before him, and the high sensitivenes of the cœsium and rubidium reactions may be best judged of from the fact that a thousand parts of the water contained only 0·00021 parts chloride of rubidium, and 0·00017 parts chloride of cœsium, or about four grains chloride of rubidium, and three grains chloride of cœsium per ton of water.

So remarkable a discovery, accompanied by so complete a demonstration of the sensitive delicacy and reliability of the method—its minutely discriminative power as an optical means of chemical analysis—at once, as may well be imagined, established the process as a new and invaluable branch of scientific investigation. This first discovery has enabled other physicists since then to discover these new elements in various other circumstances—both being found in various minerals, and rubidium being also found widely diffused through the vegetable kingdom, and in the familiar articles, coffee, tea, cocoa, beet-root, tobacco, etc.

A year had not passed over the announcement of this first great achievement of the new science ere Mr. Crooks added to its triumphs, and won the highest distinction to himself, by the discovery of the metal thallium, which he named from the colour of its characteristic line in the spectrum (that of a *green twig*) and three years afterwards Professors Reich and Richter won for it and themselves further honours by discovering the metal indium, so called from the two indigo-blue lines characteristic of its spectrum, which led them to their laurels.

The chemical properties of cœsium and rubidium have been investigated by Bunsen and Kirchhoff, who have assigned them a place among the alkaline group of metals of which potassium, sodium, and magnesium are the best known to the general reader. Thallium has been examined by its discoverer, Mr. Crooks, and also by Mr. Lamy, and found in many of its characteristics to resemble lead. Indium is allied to lead and zinc, but its properties require further investigation. But we must notice rapidly some of the other facts of the science, that we may reach, if possible, some scientific rationalia in reference to it, by which the mind of our readers may be able to form a better conception of its character and tendency.

Prior to these discoveries Sir Charles Wheatstone had made a most important set of experiments (reported in the British Association's Report for 1835) with the spark of the electrical machine and the voltaic induction spark, from which he was enabled to point out that sparks from different metals produced dissimilar spectra, and announced that thereby "one metal may easily be distinguished from another by the appearance of its spark." And this announcement was followed by investigations by Masson, Ångström, Plücker, Van der Willigen, and Despretz.

Ångström, in 1855, announced that while Wheatstone had noticed that when the two electrodes or poles of the battery were of different metals, the spectrum contained the lines of both metals—he had himself further proved that a compound of the two metals did not reveal new lines, but also gave the lines of both the metals forming the compound.

Mr. Fox Talbot had also, in 1834, observed the distinctive metallic lines given by gold, copper and zinc, deflagrated by galvanism.

Without going into further details, these researches have resulted in our having a very important set of maps of metallic lines and the lines of non-metallic elements, which form an invaluable guide to further investigation, and to the means of fixing chemical identity.

From what has been already said it will have been understood that the lines of all chemical elements have distinctive characteristics in colour and position, and in some instances also in number, and that the spectroscope is capable of detecting the presence, in infinitesimally minute quantity, of these elements—the $\frac{1}{180,000,000}$th part of a grain of sodium, or the $\frac{1}{6,000,000}$th part of a grain of lithium, for example—when their presence (on account of the smallness of the quantity) might altogether escape detection under ordinary chemical analysis.

It appears necessary to add here, that though Angström, as above mentioned, found that compounds of two metals did not reveal new lines, but gave the lines of both the metals forming the compound, yet this is not strictly true of all compound metals under all circumstances; for it has been found that compounds do give different spectra from their elementary components when subjected to a light not sufficient fully to decompose them, and that it is only when complete decomposition takes place that the spectra of the respective elementary constituents can be relied on. It is also found that greater intensity of light, or increased temperature, applied to the combustion of the elementary metals, in some instances gives rise to the production of additional lines.

SPECTRUM ANALYSIS.

CHAPTER XXVIII.

The light, or positive, lines of the Spectrum, and the dark, or absorption, lines—Their coincidence with each other—Kirchhoff's great discovery—His conclusions not a full interpretation of his facts—Further interpretation of them, and rationalia of the phenomena—Corrected explanation of the cause of absorption—Practical result—The identification of the elements of solar combustion—Our right to conclude these several elements to be in the Sun—An error at the root of the science corrected—The Spectrum and its colours not an analysis of light—Demonstration of this—The lines of the Spectrum not the less an analysis of the chemistry and elementary components of combustion.

In the preceding chapter we endeavoured to give a rapid view of spectrum analysis as applied to terrestrial chemistry, with the aim of enabling the general reader to comprehend the basis of its application to the science more especially dealt with in the present volume.

The lines given by the spectroscope from the combustion of terrestrial elements, it was there explained, were lines of *light and colour*. We now come to deal with the lines of solar and stellar spectra, which, as already announced, Fraunhofer found to be not lines of light and colour, but *dark* lines, or non-luminous interruptions to the continuity of the spectrum. Fraunhofer came to the conclusion that the darkness of these lines was occasioned by absorption; and he also observed, as early as 1814, that the dark lines, distinctively marked D of the solar spectrum, coincided in their position with the bright yellow lines afterwards found by

Professor Snow to be, definitively, those of sodium. This fact laid the basis of Kirchhoff's great discovery of 1859.

Kirchhoff, in testing, during the autumn of that year, this coincidence between the sodium lines and the lines D, after obtaining by his spectroscope a sufficiently clear solar spectrum for the purpose, placed a flame, coloured with the vapour of sodium, in front of the slit, and saw the dark lines D at once change into bright ones. He was also astonished to find that when he allowed the full strength of the sunlight to shine through the sodium flame, the dark lines reappeared with extraordinary distinctness. He also tried the oxy-hydrogen-lime-light, commonly known as the Drummond light—the ordinary spectrum of which gives no dark lines—and found that, when this light passed through a flame coloured by common salt (chloride of sodium), dark lines appeared in the position of the sodium lines. The same result appeared when platinum wire, heated by an electric current to near its melting point, was used instead of the Drummond light.

These results enabled Kirchhoff to conclude that the sodium flame *absorbs rays of the same degree of refrangibility with those it emits, and that it is transparent to all other rays.* This mode of reversing the bright lines, or converting them into dark ones by absorption, has been tested by numerous experiments, with other elements, since, and fully confirmed.

We will now endeavour to explain the rationalia of these phenomena in such a simple manner as will possibly enable the reader fully to understand their cause. For this purpose we will take the liberty of *assuming* (and we think we could prove it if our present limits permitted so great a digression) that all light and heat are manifestations of electricity, under varying conditions and in varying degrees; that electricity and white light are identical; and that the three red, yellow, and blue tints into which light is divisible when subjected to prismatic refraction, are not occasioned by any want of homogeneity in white light or in electricity, which we *assume* to be the same, but in the greater or less degree of obstruction which light encounters, and the greater or less amount of refraction it undergoes under the action of the prism or in the combustion of particular bodies. Thus the blue tint of the spectrum undergoes the greatest amount of interruption and refraction from the prism, and has, consequently, to exert the greatest and slowest operating amount of chemical action in conquering the opposition or acting under the effect of it. The red tint undergoes less refraction and interruption, and therefore operates with a more concentrated and immediate action and a greater heating and dissolving power; while the yellow tint suffers little or no refraction, and passes onward as a luminous manifestation with little deterioration of its intensity. In perfectly transparent bodies, or in media which do not dispersively refract or obstruct the passage of light, the homogeneous white light passes through and onward without exerting any chemical action or heating power, though it has never been doubted that in doing so it carries the blue chemically active rays with it as well as the red heating rays; for they are found in the white light after passing through such media whenever the spectroscope is applied to it. Why, then, is it that the red and blue rays are neutral under such circumstances—where their power, from its concentration, ought to be greater—but just because, when they do manifest their peculiar action, it is only where they are proportionally interrupted or impeded in their direct action? It is nonsense to say that the blue rays are the chemically active rays, and that red heating rays have no chemical activity: as well tell us that the heat by which metals are smelted, and compounds dissolved, is not characterized by chemical action! The case is altogether different, and the language is at present most misleading. The blue rays are chemically active under circumstances within which the red or heating rays would not act with the same minute *weakness, progressive operation, and delicacy*, but would act more powerfully and with a totally different and stronger chemical effect; *therefore the red rays will not produce the delicate impressions and photographic results obtainable from the feebler and more minute action of the blue rays.*

Let us now consider these peculiarities of white light with reference to Kirchhoff's discovery. It would follow from what we have just explained, that the yellow light manifested by sodium under combustion is no part of sodium itself, but is that degree or proportion of white light or electricity which is necessary to the combustion of sodium. It burns, in fact, at less than a white heat or light under the given conditions—its flame point (or shall we say point of individual and elementary distinctiveness?) being that of the yellow tint. And this tint is occasioned by the obstruction it affords to the full combustible action of electricity as white light. It diffuses the electricity or light at the yellow point of its combustion, and will not sustain it till it reaches the intensity of white light. In like manner thallium will not, under given circumstances, sustain combustion beyond the intensity of the green flame. To sustain their combustion, therefore, these bodies must have a continuous supply of electricity sufficient to reach the points of green or yellow manifestation respectively, otherwise their combustion could not proceed; and, under certain conditions, they will not sustain a higher combustion: in other words, they must have just as much of it supplied to them as they give out. That electricity is universally diffused, and presents an ever ready reservoir for such a supply to be drawn from, is already sufficiently understood. But electricity acts in the readiest way, or we may express it, always selects the easiest means of action; and Kirchhoff's experiment proved a little more than the inference he drew from it, or merely, that the coloured flame absorbs rays of the same refrangibility as those it emits; for he found that, with a tolerably bright solar spectrum, the sodium flame, with a Bunsen's lamp, threw the bright sodium lines upon the solar spectrum with unexpected brilliancy; but when he allowed the full strength of the sunlight to shine through the sodium flame, he saw the dark lines D reappear with extraordinary clearness.

In fact, Kirchhoff's experiment proved—though we do not find he has so noted it anywhere—that, of two flames or lights of different intensities, containing sodium or the sodium lines, the stronger flame or light will absorb the light lines of the weaker flame or light; and subsequent experiments have also proved the same unnoted fact. The weaker flame is dark against the brighter flame. In other words, the intenser manifestation of electricity or light is drawn by the stronger from the weaker flame, as the readiest and easiest means or source of supply, and the weaker flame is therefore left *minus* the intenser light. It is still the old principle that blackness is not positive, but negative; it is light withdrawn or withheld. A glance at the diagram, illustrative of the facts, will prove this, and show how the phenomenon, though leading to the same results, has been misunderstood at its own point in the progress of the question. Thus:

Fig I

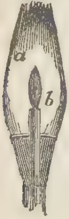
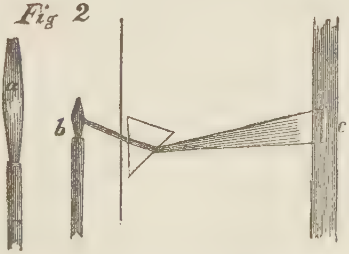


Fig 2



In fig. 1, the flame *a* is a more powerful flame of sodium than the smaller flame *b* interposed between it and the observer, and we find in consequence that the weaker sodium flame is dark against the more powerful flame behind it; but to show that this is not occasioned by the nearer flame absorbing the yellow rays of the more distant flame, but by the more distant flame absorbing the light of the nearer one, it is only necessary to observe fig. 2, where we have a side view of the two flames, and of their effect on the spectroscope. In this case it is the fact, that if the one sodium light *a* or *b* alone be subjected to the action of the prism, the sodium lines in the spectrum *c* will be the usual yellow sodium lines given in light and colour; but if both flames be used in the position indicated, the sodium lines of the spectrum will be, not the luminous yellow lines, but dark lines; and the inference of Kirchhoff is, that this is caused by the flame *b* "absorbing rays of the same degree of refrangibility as those it emits." But, observe, the flame *b* is emitting no sodium rays to the spectrum, but it is really giving dark bands there instead of rays or light, which it would send were it the only light, or were the light *a* withdrawn. Now the question is, why should the flame *b*, whenever the flame *a* is placed behind it, absorb the sodium lines from *a* passing to *c*, which *b* is then no longer itself emitting to *c*? This is not absorbing the rays *it emits*, but absorbing the rays it does *not emit*. Why should, or how can it absorb the sodium rays, and retain also its own sodium lines, and manifest only dark lines in the spectrum *c*? By this explanation a double amount of sodium light is at *b*, and only darkness as the result of it! But if we reverse the lights, the whole affair is explained; and Kirchhoff's experiment with the sunlight does so explain it. Whenever the sodium lights, or lights with sodium lines in them, are so placed that the stronger light of two or more is nearest to the spectroscope, the usual sodium lines will appear in the spectrum with their usual light and colour; but whenever the weaker sodium light is placed nearest to the spectroscope, the place of the sodium lines in the spectrum will be occupied by dark lines. This, we say, Kirchhoff *proved,* though he did not so *interpret,* fully; for he found that a strong sodium flame interposed between his spectroscope and a weak or modified solar light enabled his sodium flame to manifest the luminous sodium lines in the place of the dark sodium lines of the solar spectrum; but whenever he allowed the full intensity of the solar light to operate behind his Bunsen flame, or reversed the intensity of the lights, he instantly also reversed the effect in the spectrum, and developed dark lines there in the place of the luminous sodium lines. Now, this was clearly not because the Bunsen sodium flame absorbed the luminous sodium lines of the sun, for the sun gives no luminous lines, but only dark lines, in the spectrum; nor was it because the Bunsen flame absorbed or retained its own sodium lines, but because the stronger light absorbed the sodium lines of the weaker, and reversed the direction of its radiance. In other words, the stronger sodium flame absorbs the same rays it gives out from the weaker sodium flame, but the weaker flame does not absorb the rays of the stronger. Light is manifested to the human vision by rays falling upon the retina; but if the rays be passing away from the retina, no manifestion of light will be made conscious to the eye—there will be darkness instead; and so it is with the manifestation of the spectrum. The stronger light, when placed nearest to the spectrum, will still give luminous lines in the spectrum, when two or more lights of different powers or intensities are used; but when the weaker light is placed nearest to the spectroscope, its luminous lines will be withdrawn in the direction of the stronger light beyond it, and away from the spectroscope, and only dark lines instead of luminous ones will appear in the spectrum.

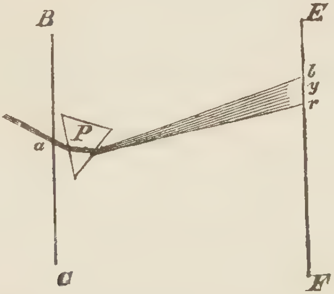
This, however, comes to much the same practical result in the sideral and solar investigations of the spectroscope, and in no way qualifies Fraunhofer's conclusion that the dark lines of the solar spectrum are evidences of absorption external to the terrestrial atmosphere, or Kirchhoff's great conclusion, that sodium and other elements exist in the sun, and that the spectroscope enables us to demonstrate the fact by the absorption of these lines; for that is the next step in the achievements of spectrum analysis which we would now point to.

Kirchhoff, following up the experiments before noticed, made further investigations on reversing the light lines of various elements, and, as the reader will now, we think, be able to perceive, came justifiably enough to the conclusion that those which could be so identified with the lines of the solar spectrum were identical with the elements in the sun from which these lines were produced. Many of the elements of our terrestrial chemistry exhibit a very great number of lines. Thus Professor Ångström has noted 450 lines of iron alone, 118 of titanium, 75 of calcium, 57 of manganese, 33 of nickel, 9 of sodium, etc. And more could be produced from all these substances by increased temperature. If, then, Kirchhoff was able to identify one-fourth of the lines of iron in the dark lines of the solar spectrum, or ten of the lines of nickel, or four of the sodium lines, it is no extreme assertion to maintain that there is, in this, positive and sufficient evidence of the existence of these several bodies in the physical composition of the sun. In this way Kirchhoff, Ångström, Thalén, and others have found the evidence in the solar spectrum of the sixteen following elements: aluminium, barium, cadmium, calcium, chromium, cobalt, copper, hydrogen, iron, magnesium, manganese, nickel, sodium, strontium, titanium, zinc. And they found that all the bright lines given by these bodies exactly coincided with dark lines in the solar spectrum; and the conclusion is, that the coinciding dark lines in the solar spectrum are caused in the solar atmosphere by the glowing vapours of these respective bodies absorbing the bright lines emitted by the respective bodies themselves in a state of combustion nearer to the sun. It is no challenge of the practical result when we say, in accordance with the explanation we have before given, that the absorption in the sun takes place, not by the glowing vapour of the metal absorbing its bright lines, but by the dominant light of the metal nearer to the body of the sun absorbing the bright lines which the glowing vapours would otherwise give forth, and thereby reversing the direction of their specific radiation.

As we have already mentioned, the light given forth by these elements is no part of the elements themselves. If we observe any element, though the radiation of its combustion diffuses itself in all directions, not an atom or molecule of the element itself is diffused with or in the form of radiation. Chemistry has already too fully proved to us that the whole amount of the element may be reabsorbed and reproduced to leave us in any doubt on this point; and this fact alone is a demonstration that light is something altogether apart from the body or element it deflagrates; that it is, in fact, identical with the great deflagrating agent, electricity. Indeed, there is no agent or agency we possess the slightest knowledge of which could supply light and heat, and their action, but electricity; and it manifests a most unusual fastidiousness on the part of scientific men to deal so shyly with a fact so well evidenced and so far reaching in its explanations. We can produce electricity and electric action from light and from heat, and we can reciprocally produce light and heat and their actions from electricity. We have no stronger proof that water is composed of oxygen and hydrogen than this. All the demonstration we can give of the composition of water is only that we can produce oxygen and hydrogen from water, and can reciprocally produce water from oxygen and hydrogen. Yet who of those still in doubt as to the former demonstration, that electricity is composed of light and heat, would hesitate to accept as absolutely conclusive the latter as to water being composed of oxygen and hydrogen?

In a previous page of the present chapter we have used a very strong expression which we now revert to for the purpose of showing that it is justifiable on the grounds of science, and capable of being vindicated by absolutely irresistible demonstration. We refer to the remark, "It is nonsense to say that the blue rays are the chemically active rays, and that the red rays have no chemical activity," etc. And we refer to our whole remarks in connection with the subject, from a desire, in the interests of science and its future advancement, to disencumber this new and eminently important line of investigation of a great primary error and misinterpretation, and to show that many results and observations of great value, which have been unhappily united to this misconception, are in no way dependent on its accuracy for their practical importance. At first sight our remarks will appear to express a challenge of the accuracy of Professor Tyndall's experiments on calorescence. A little consideration will show that nothing of the kind is either intended or involved, though a new explanation of these experiments and their causes may be a necessary result of what we are about to prove.

We have held for more than twenty years now, with ever increasing conviction of its truth, from hundreds of instances concurrently operating to corroborate it, that the different colours of the spectrum are only different degrees of intensity in the manifestation and action of light—the blue being the weaker, the red stronger, and the yellow the strongest, short of white light. But it is by means of the principle involved in the spectroscope that we at length possess the power of demonstrating to others the absolutely irrefragable accuracy of this early conclusion. Newton held, and it has been held, and, we may say, implicitly accepted by all others since his time, that the colours of the spectrum were an analysis of white light. In other words, the conclusion as adopted by modern science is, that blue forms a definite and unchangeable portion of white light, red another and distinct portion of it, and yellow a third distinct portion. We do not hold Newton entirely responsible for this acceptation of his experiments and their interpretation; we merely point to what the state of the acceptation is before calling attention to a simple experiment in proof of its error, and one which any person may easily verify for himself, with the following diagram and explanation for his guide.



If a prism P be applied to a slit *a*, through which light is admitted, it will develop the spectrum at *b*, *y*, *r*, on the screen E F in the usual tints, blue, red, and yellow, with their subordinate and intermediate tints, the yellow being the least refracted part of the light admitted by the slit, and the blue and red being on each side of the yellow; but if the slit *a* be so fitted that it is capable along with the prism of being slid upwards to B and downwards to C, along the whole distance from B to C, it will in doing so develop the colours of the spectrum at every point of that distance, in succession, on the screen between E and F, and always throughout in the same order, the yellow being always between the blue and the red Now what is the remarkable significance of this extremely simple but very pregnant fact? It is this, that every part of the whole light between B and C, passing through the prism when slid up and down along with the aperture *a* between these two points, becomes blue, yellow, and red, and then blue again by turns, or red, yellow, and blue, and then red again by turns, just as the prism is slid upwards or downwards. In other words, the portion of the slit of light which at *a*, as a *fixed* position of the slit, passes through the upper part of the prism, and is developed in blue on the screen E F at *b*, will, when the slit and prism are pushed upwards, pass in succession through the same parts of the prism as those through which the yellow and red rays below it are respectively refracted; and when it does pass through these parts of the prism, it will, instead of remaining unalterably blue, become yellow and red at these respective points, showing that its original colour blue was not due to its intrinsic physical character as an elementary blue constituent of white light, but was entirely due to the part of the prism through which it was refracted, or the specific amount of its refraction. So that when the so-called blue portion of the light passes through the portion of the prism by which the red or yellow is refracted, it is no more inherently and materially blue than red or yellow are blue, but owes its whole *elementary* character and distinctiveness to the special operation of the prism alone. And in like manner red becomes by turns yellow and blue, and yellow becomes blue and red, just according to the parts of the prism through which they are respectively passed. There is, we say, in this experiment absolute demonstration that no such colours as blue, yellow, and red, or their intermediate tints, have any fixed elementary existence as constituents of light, but that the whole phenomena of colour are due exclusively to prismatic action or refraction, or weakened energy. This is important so far, as a demonstration, irresistible and conclusive, that *the spectrum is not an* ANALYSIS, *and its colours are not*

ANALYTICAL *constituents or components of light.* But here, be it observed, as essential to perfect fairness, Newton was not much to blame for missing this corrective conclusion ; for he dealt with a round hole, as we have before mentioned, and not with a slit, as Wollaston and Fraunhofer, and other observers since their time, have been doing. Indeed, we are far from thinking blame is attributable anywhere ; all we mean to say is, that the fact now pointed out was certainly much more within the compass of later observations, aided by the improvements of the spectroscope, than within the grasp of those comparatively rude means of observation which Newton's magnificent intellect had to contend against.

The above results, we would now specially remark, are no disparagement to the important experiments of Professor Tyndall, on calorescence. They do not prove in any way that when the light passes through that part of the prism which refracts or develops it into blue, it is any less blue in that condition than before, or that, as blue, it is any less or more chemically active than he has found it to be. They only show that it admits of being passed through a different part of the prism, and that when so treated it ceases to be blue and to have the specific chemical activity he has identified with blue ; that when changed into red or yellow it has those qualities which he has identified respectively with red and yellow. If we do not go further into this part of the question here, we beg leave to say that it is because space and the special nature of the present work forbid our indulging in a digression so great as the extent of the subject would require, and not from any undue estimate of its importance, or want of materials or preparation to deal with it. We claim to record it as a duty necessarily postponed, to become the subject of a separate and special work.

But, to return to the main current—though the spectrum, as we have said, is not an analysis of light, and colours are not fixed and elementary in character as analytical components of white light, it is still not the less true, as we shall see in the succeeding chapter, that the lines in the spectrum *do* indicate what are the chemical and elementary components of combustion. In truth, we only get more clearly at that conclusion by eliminating the error we have just detected.

SPECTRUM ANALYSIS.

CHAPTER XXIX.

Proofs that the lines of the spectrum indicate the components of combustion, etc.—Identity of elementary spectra in the present state of the science—Causes of the distinctive spectra—The evolution of elementary light and the application of this to the spectrum—The specific combustion points of different bodies—Prismatic action on lights of specific energy—The transmission of light—The laws of specific combustion and radiation, and their application to the spectrum—True cause of the analogy between the tints of colour and the notes of music—Explanation of pigments and coloured surfaces—More errors of theory corrected.

We have said, that though the spectrum is not an analysis of light, and its colours are not fixed and elementary components of white light, it is still not the less true that the lines in the spectrum indicate what are the chemical and elementary components of combustion.

Let us try if we can now make our way perfectly clear and sure to this conclusion. The colours of the spectrum, as we have seen, are liable to change whenever the circumstances are changed, and to become—the yellow colour, blue and red; the red colour, blue and yellow; and the blue colour, yellow and red; just according to the point at which they are respectively passed through the prism, and subjected to its different refracting powers. But it must be obvious that the lines of the spectrum are also, under the same experiment by which we proved this, liable to change in their position, and each line to appear at every point of the distance between E and

F of the screen figured in our last illustration (p. 317), as well as each particular colour of the continuous spectrum; and that therefore there must be, from the points B to C, between which the slit admits of being moved upward and downward, a continuous radiation of the light given in the line or band of the spectrum. Thus, if the line be that of any given element, say the yellow sodium line, there must be a radiation of this sodium light falling upon the surface B C at every point between B and C, because at every point between these extremes the prism encounters it in being slid up and down, and renders it in the spectrum. But then observe the important distinction which here occurs. The yellow sodium lines will only appear through certain parts of the prism. They will not give a continuous spectrum, and though it is quite true that there are other sodium lines in other portions of the spectrum, and that the portion of the sodium light which gives the yellow lines at one position of the slit, must, in sliding the prism upwards or downwards, give the other sodium lines, and these others in turn become the yellow lines, yet the portions of the prism between the refracting points of these several lines of sodium are powerless to render the sodium flame, and (*to appearance*) cannot transmit, or render, or refract it at all.

The determination of such a fact is of inestimable importance to chemical science; and if, as we find to be the case, every other chemical element has its own particular and distinctive parts of the prism through which the rays or light from the flame of its combustion will be manifested, and equally refuses to be visibly refracted or transmitted through any other portions of the prism, why then, we say, that here undoubtedly we have, by means of the spectrum lines, the distinctive evidence of each particular element of chemistry subjected to combustion placed within our reach with a certainty which admits of no possible challenge or doubt.

Such, then, is so far the condition of spectrum analysis on the facts and experiments already before the public. May we not, however, be permitted to penetrate a little further, and inquire why elementary chemistry, or chemistry subjected to spectroscopic investigation, is thus developed in lines, or in special portions only of the spectrum? Be it here observed, we place little importance on the phenomena of mere lines; for we have already found so much to depend on the *modus operandi*, as before shown, that we cannot say, in the present condition of the spectroscope, whether the development in *lines* be not due to the prism more than to any specific question of elementary chemistry involved, or to the precise position which any element occupies or asserts for itself in the distribution or diffusion of light. We are quite content, without exacting too much from it, to find that the prism gives us a positive distinction between the refrangibility of light from one chemical element and another, and to accept the fact that this distinction is accurate enough for practical purposes, though its present manifestation be only the *prismatic mode* of showing it. Without, therefore, insisting much on the term *lines*, it is of sufficient value to our present inquiry to know that elementary bodies have each a certain specific refrangibility under given circumstances, and will only appear in certain portions of the spectrum. And though the full answer to our investigation belongs rather to chemistry than to astronomy, and must therefore be reserved in the meanwhile, it will aid us somewhat, in our present treatment of this subject, to place a few features of that answer now before the reader.

It is obvious, then, that when compound bodies are subjected to sufficiently strong combustion to reveal in the spectrum the elementary lines of their chemical components, it is because the heat of the combustion is dissolving the compound, and reducing it to an analytical development of its separate elements; and that when any element is rendered transparent by being elevated from the solid to the liquid, or from the solid or liquid to the gaseous state by heat, it has in that state a specific power of radiating, more or less, the light which it contains; and that the exercise of this radiating power takes place, in the first instance, when the pure light of the combustion is transmitted in a modified form through and from the gases evolved by the decomposition of the chemical element or elements under deflagration, combustion, or volatilization; and that this primary specific radiation is repeated, with prismatic modification in the spectrum, by that portion of the light transmitted under its influence, and is not repeated by those portions of the light which are not subjected to it in the first instance, or which escape from the flame of the combustion without passing through, or without being radiated by, the elementary gases evolved.

The question is one of an extremely elaborate character, and, though prepared to pursue its investigation a good deal further through its various ramifications, it is with regret we have to say that we cannot do so within our narrowing limits here—which are intended for general readers more especially—without involving the details of various collateral sciences which were not in contemplation at the outset of the present volume. We must endeavour, therefore, to be rather sketchy than exhaustive in our explanations, that we may neither overtax patience nor protract our present adieu by drowsing upon the doorstep. One of the questions primarily involved is—what is the law of refraction, or rather, what is the primary principle on which it proceeds? for something like the rule it follows may be gathered from any treatise on optics, and yet the wherefore of the rule no nearer attained to. Now the principle of refraction we hold to be this, that light invariably takes the shortest *available* course through any transparent or interrupting medium, compatible with the direction of its first impulse, under the general law that all direct motions and forces pursue the shortest path, and when interrupted adhere to that path as closely as the nature and amount of the interruption will allow. Thus, when light falls on a transparent medium, in a direction perpendicular to the plane of its surface, it passes directly through the interrupting medium without suffering any refraction whatever; but when it falls obliquely, or at an angle, upon the surface of the transparent medium, it takes a shorter path than its own direction through the medium, and its direction, or the line of its refraction, is a common measure of the intensity of its own momentum or power of penetration, and the amount of the interruption to which it is subjected. This being understood, the question next arises, how do elementary bodies, developed into the gaseous form under the influence of combustion or volatilization, disperse their expanding gases from the centre of combustion by which they are developed?

This, we think—where special circumstances do not modify it otherwise—may be very safely answered by analogy with which we are familiar, and by an application of laws, of which science leaves us in no manner of doubt. First, we know that an expanding homogeneous body expands equally in all directions where the media in all directions around it are of equally resisting or equally yielding power. These gases, therefore, evolved by combustion in an atmospheric medium, must at the outset tend to disperse themselves in all directions around the centre of combustion equally, or in the form of spherical expansion; but this can be the condition of things at the ouset only, for immediately afterwards the following modifications will begin to operate:—First, the air below, which is heavier and more resisting than the air above, to a gas lighter than itself; and, secondly, the lightness of the gases evolved, which must from that cause have a tendency to rise to a higher level; so that though, from the first necessity for immediate accommodation, the several constituents of a compound evolved in gases will take, as their evolution proceeds, the form of spherical expansion at the outset, this will not be continued. But what we have to do with is that it will continue as long as the time required for all light, passing with the usual rapidity from the centre of combustion, to be radiated outward with the expanding spheres in every direction; for this light will evidently have passed outward through the expanding spheres of gas long before they have had time to recover from their first form of spherical dispersion, and take the modified direction prescribed by their own buoyancy and the inequalities of atmospheric resistance. Therefore the light will have suffered whatever degree of specific action or energy the gases can impart to it while the gases are still in the form of transparent spheres of gas universally diffused around the centre of combustion, even rapid as their diffusion doubtless is. Then let us consider, where a compound of two or more elements is being so developed into gases, in what order their development would proceed. Now we know from independent chemical investigation that each separate chemical element has its own specific ratio of expansibility, and that where it is evolved in gas, each elementary gas has its own specific gravity, its own specific expansibility, and its own greater or less rate of development into its gasiform state, under a given sublimating or volatilizing heat. We are therefore fully warranted in saying that where a compound is dissolved, and its components are evolved in the gaseous form by combustion, the respective gases will be dispersed from the centre of emission in successive and alternate spherical layers of gas, in the first instance, the succeeding layers being interior to, or concentrically within, those first evolved, and separation only taking complete effect after the spherical form of their first development has been broken through by their overcoming or losing the impulse of general expansion, and yielding each to its own specific gravity and law of buoyancy and elasticity which is the cause of its superior chemical affinity for its own volume.

And now, with these considerations, which are, perhaps, sufficient for our present and more immediate purpose, let us revert to the spectrum and its means of elementary identification; for we feel that we are now qualified to grapple with its peculiarities, and extract its principles and rationalia in a much more satisfactory way for the comprehension of a general, if not also a scientific, reader. It will be apparent from what we have said, that the light forming the means of combustion in evolving the elementary gases through a deflagrated or volatilized compound, will pass outward through the expanding spheres of these gases in all directions from the centre of emission—which coincides with the centre of the gaseous spheres—by the radii of these spheres produced beyond them, and that it will therefore pass through them in such a way that it will suffer no refraction from them properly so called. What, then, will be the nature of the modification which the light undergoes in passing out with these respective gaseous spheres? For *that*, or *its effect*, is what it repeats on the application of the spectroscope afterwards in giving us the spectrum of the specific flame. Can the modification sought for be the greater or less facility which the elementary gases give to the diffusion of luminosity or radiation?—the slower and more difficultly evolved gas impeding and protracting, and the more rapidly evolved gas hastening and intensifying the initial impulse of the radiance diffused? We believe we can make it absolutely certain to the mind of the reader that it is so, and that the whole explanation is of extreme beauty, and invested with those charms of symmetry, logical fitness, and application, which are the preeminent characteristics of all great truths.

Let us take, irrespective altogether of spectrum analysis and of any question affecting its accuracy, the condition of chemistry upon the accepted testimony of chemical analysis and experiment, and we find that different elements undergo combustion and volatilization at different temperatures, and are evolved in the gaseous state with the manifestation of light in differing degrees of intensity, and with different powers of luminosity. That each element under its own specific combustion point, if we may be pardoned the expression for the sake of its convenience, will emit a quantity of light just capable of being radiated through our atmosphere outward from it to the limits of a certain spherical area of space of which it forms the centre, and that beyond the confines of that area it will be invisible. There is thus demonstration of a specific space-penetrating power of light—depending on a specific initial energy—in the case of each element under combustion; and this applies to the power of light to pass through all obstructive but penetrable media. The law may therefore be expressed thus: *The light emitted by every elementary body at its combustion point has, in diffusing itself through impeding media, a specific penetrating power identifiable with each particular element.* In fact, in this respect each element is just as distinct in its specific characteristic as it is in its specific gravity, density, combining proportion, etc. But then the question may arise, and it is as well to dispose of it at once: When bodies are subjected to combustion or volatilization by means of the electric spark, they are evolved in gases generally at a temperature above their mere specific combustion points; and does it not therefore follow that the law applicable to their combustion points cannot, under such circumstances, hold good? To this question the answer furnished by chemical experience is happily very conclusive; it is, that whatever degree of temperature be applied to two or more elementary bodies, these bodies will be affected by it in the ratio of their own specific expansibilities, etc.; so that the *ratios* of the respective combustion points are maintained at all stages of combustion of greater or higher intensity. Thus, then, we have it chemically determined that elementary bodies subjected to combustion maintain under that combustion, whatever be its intensity, the characteristic ratios of their own specific combustion points, and that this is the condition and operation in them of combustion flames employed for the purposes of distinctive spectrum analysis.

Let us now consider the nature and operation of such a medium as a prism interposed to the specific penetrating powers of lights of different degrees of energy. It must be obvious that where an obstructive medium is interposed, the different lights will be affected by it according to their different energies, and that if the medium were extended indefinitely, none of the lights would pass entirely through it, but each of them, according to its energy, would penetrate only a certain distance into it. Thus, for instance, if a prism were a few miles in diameter, probably very few lights which we can bring to the highest combustion point would be able to penetrate through and beyond it, and it is certain most of our ordinary artificial lights would not penetrate half through it: each of them terminating at a point of invisibility of its own. But a prism is a body of unequal diameters; and supposing we could so arrange that the different lights falling upon one of its sides should pass through it in such an order that—of three lights, *a*, *b*, and *c*, of different intensities, *a* being strongest, *b* next, and *c* weakest—they should have—*c* the shortest diameter of the prism from its point of impact, *b* the next, and *a* the longer diameter of the three; it is quite conceivable that in such a case the weaker light *c* might be visible beyond the prism, while the stronger lights, *a* and *b*, were unable to penetrate through it. At the same time it is quite certain that if all three passed through the shortest diameter, the strongest light would render the others invisible, and be dominantly manifested as if it were the only light of the three which had power to pass. But where all three had power to pass through all the three diameters of the prism—consisting of the shortest diameter and that on either side of it—the strongest light would by its energy take possession of all the three diameters by its dominance, and the other two would not be appreciable because of it. How then is it that we have here three or more lights, or rays of elementary combustion, manifested by the prisms of the spectroscope in one spectrum? To answer that question we must fall back upon another feature in the laws of light.

Whatever be the mode in which light in free space is transmitted from one point to another, there can now be no doubt that in atmospheric or other media it acts in undulations, or vibrations, and expanding waves—like those made by the circles flowing outwards from the point at which a stone impinges in water, or, more appositely, a sound impinges in air; though these undulations are of intense rapidity as compared with the velocity of sound in such media, and are far too rapid for our vision to be conscious of them. In fact, very considerable interruptions or intervals may take place in the continuity of light, without our being able to detect them by means of the eye merely; as is well exemplified by the ring of light made by a fiery stick, the point of which is at but one part of the ring at a time, though we see it as if it were continuously at all parts of the ring. Now, apply these facts to the operations of the spectroscope, for they are undoubtedly part of its phenomena, and combine it with our previous observations, and the following will be something like the state of the case:—

1. The gases evolved from a compound body, under combustion or volatilization, expand in the first instance from the centre of emission in spherically expanding layers or gas bubbles, similar in form to the soap bubble, or probably, from their lightness, with an elongation upward, but ultimately each gaseous bubble drawing together into a volume of homogeneous gas, and floating upward to the level of its specific gravity.

2. The bubbles of different gases so evolved by combustion or volatilization follow each other outward from the centre of emission in some ultimate order, compatible with the nature of the compound, and with the laws of chemical evolution, into which it is irrelevant to the present investigation to inquire.

3. The light radiated with each elementary gas on its emission possesses the ratio (applicable to the temperature of the combustion or volatilization) of the specific combustion point or volatilizing point of that element.

4. Between the successive evolutions of gas, pure white light also passes outward from the centre of emission, and diffuses itself in radiation.

5. The evolution of the respective gases facilitates more or less the diffusion of the light, by increasing or decreasing its initial energy, and each in a specific degree of its own.

6. The light of combustion or volatilization diffuses itself through surrounding media in undulations; but this light, facilitated or modified in its initial energy by the respective gases evolved, diffuses itself at brief intervals of interruption, in consequence of the successive and alternate evolution of the gases where a compound body, or more than one element, is subjected to volatilization or combustion.

7. The sustained and continuously permanent manifestation of the lines of the spectrum is only apparent, but not real,

where successive gases are evolved from the source of light; and no more continuous, though so appearing to our vision, than the fiery ring described by the incandescent point of a piece of charred wood.

8. Light is capable of two modes of increased or diminished action, viz.:

    1. By increased or diminished intensity or rapidity of diffusion or initial energy.

    2. By increased or diminished quantity or magnitude of the point or source of radiation or flame.

9. (Corollary of No. 8.)

    1. Colour is a result of increased or diminished intensity, initial energy, or rapidity of diffusion, comparing one degree of this with another.

    2. Comparative distinctness, or visibility, is a result of quantity rather than of initial energy, though—quantity being equal—the stronger colour, in point of initial energy in the order stated in No. 11, will be the most visible or distinct.

10. Elementary bodies, subjected to combustion or volatilization, differ each from the other in the colour or initial energy of the light they emit, even though their respective lights may be equal in quantity, and a blue or red light may be more distinct than a yellow light, from being superior in quantity while still weaker in initial energy.

11. The tints of light stand in their comparative initial energy to each other in the following order, the stronger being at the top, the weaker at the bottom of the list:—

1. Yellow.
2. Orange.
3. Red.
4. Green.
5. Blue.
6. Indigo.
7. Violet.

And none of the tints of inferior initial energy can be raised by prismatic refraction to the energy of a tint above it in the list, because such refraction is *a weakening and not an intensifying influence.* Hence, though green may be produced by a mixture of yellow and blue, Newton found it impossible to analyze the green rays of light into these components by the interposition of a second prism subjecting them to further refraction—the reason, though then unperceived, being that he could not raise any part of the green by refraction to the initial energy of the yellow, and without separating the yellow he could not develop the blue.

12. Light proceeds from any luminous point outward into space in the direction of the radii of those increasing spherical areas of surrounding space, of which the point of luminosity is the centre, and so long as it proceeds in those radii it is of the same initial energy and colour, modified only by the impeding medium passed through, whether elementary, compound, atmospheric, or prismatic, etc.; but by the interposition of a prism the angularity of those of the radii which pass through it is expanded or rendered wider and less acute; so that if the lines of such expanded radii were produced backward till they met, they would meet and cross each other before being extended back to the original point of luminosity, and would never reach that point even in the case of the direct-vision spectroscope.

13. A prism expands the angularity of several radii of light passing through its different diameters in unequal degrees, and so alters unequally the initial energy or intensity of the several radii.

14. Light (whether it be electricity or not, and leaving out of view that question for the present) is an element distinct from any of the elements of combustion from which it is evolved, and extends throughout the whole length of the visible spectrum.

15. Where several spectra overlie each other, produced by the combustion or volatilization of several chemical elements,

they each extend the whole length of the visible spectrum, though only apparent to our vision in parts of it, the reason being, that such spectra are all of less intensity than white light—though all of them may be of greater intensity than the colours to which white light is reduced when subjected to prismatic refraction—and that, while none of the spectra of metals is discernible in white light, by reason of its greater intensity—whenever the white light is reduced in its intensity by prismatic refraction, yellow, red, and blue lights, etc., of greater intensity or initial energy than the yellow, red, blue, etc., of *such reduced white light* shine through these respective tints of the reduced white light at the points at which its tints are weaker than the respective tints of the metallic spectra. So that though the metallic spectra are continuous, they are overlaid and rendered inappreciable at other points by the superiority of intenser portions of the reduced white light, and are only visible at certain points.

16. (As a corollary of 15.) A yellow light, such as that of sodium, will, beyond the point at which it is visible in the yellow tint of the spectrum, suffer more by refraction than the white light along with which it is manifested, so that though the white light be reduced to red or blue it will be of greater intensity than a yellow light refracted to the same points of the spectrum; and so of the red line of rubidium, the green of thallium, the blue of indium, etc., and only where the luminosity from these respective metals is increased in greater quantity than the white light will they reveal themselves at other points of the spectrum.

17. Lights of different colours, so appearing through the various tints into which white light is reduced and spread out by the spectroscope, will, though not continuously radiated, but only radiated at short periods of intermission from the successive evolving operations of combustion or volatilization, appear continuously sustained to our vision.

As a prevailing rule, white light, when passed through the prism, suffers less extended dispersion in the colours of its spectrum than light from bodies under compound or elementary combustion; and the spectra of such bodies do not therefore co-extensively underlie the spectral colours of white light, but extend beyond their maximum and minimum points at various places, and so are revealed through the overlying spectrum.

We regret that we cannot devote more space to this interesting subject here, and beg to apologize for the fact that our explanations, for the sake of brevity, have been reduced to somewhat of the appearance of dogmatism. Scientific readers will know well enough where many, if not all, of our propositions may find support and even demonstration, but it would be asking too much to expect that we could in this place invoke the very extended sciences of electricity and chemistry, as well as general physics, to bear out the special conclusions we have been enabled to arrive at; more particularly as many of our deductions from these involve some degree of conflict, and, possibly controversy, with conclusions at present in favour, and with which it would be, to say the least, highly inopportune to incumber a volume like the present.

We will proceed, therefore, in our next chapter to dispose of what remains of the subject of spectrum analysis as applied to the great science of astronomy with which we are here more especially concerned; only pausing to explain to the general reader—to the man of science it would be superfluous—that, formidable as the preceding propositions are in numerical range, they are very far from the *whole* facts, even if we could comfort ourselves with the delusion that we had penetrated them all. But before we can proceed further in a satisfactory manner with the subject of spectrum analysis we must deal separately from the present work with an anterior question far more profound, though perhaps less complex, than the present, and which may dilute a good deal of our present language, of which we have in consequence been less careful than otherwise we would have been had we felt that we were dealing with definitions absolutely and technologically fixed.

One result of our investigations on prismatic colour, of considerable interest to science, we may here note; viz., that light not only diffuses itself through atmospheric media by vibrations, but that the prismatic tints have different degrees of vibratory intensity, increasing from the blue upwards to the white light, and that by this fact the long-known analogy, or as we may now call it alliance, between light and sound is at length explained and completed; the three notes, tonic, third, and fifth, and seven notes of the stave, being vibrations of different degrees of intensity, as has been fully established, increasing from the lower note upwards, which, impinging on the tympanum, affect distinctively the sense of hearing; and the three primary colours, as they have been called, and seven tints of the spectrum being also vibrations of different degrees of intensity impinging on the retina, which in like manner affects the sense of vision. It *is also quite certain* that there are different pitches of colour, as well as different pitches of sound, and that the same colours are capable of being produced by different instrumentalities, as proved by the spectroscope when different spectra overlie each other, just as musical notes are capable of being produced by different means, when the harmonies of concerted music are rendered by various performers and instruments, or instrumental arrangements. There is nothing, therefore, so extravagant in the blind man's idea, that the trumpet-note gave a scarlet sound. To him it is quite probable that the retina was like the sensitized plate of the photographer, all the more delicate and impressible because the opaqueness of the crystalline humour may have protected it from the direct action of light; for it is certain that by custom we sometimes make our faculties capable of only one kind of use, though they may have primarily more than one power of perception; and hence, from subjection to a specific habit, the retina of those who see may not be so delicate, sensitive, and unvitiated as that of those whose blindness does not result from defect in the retina, but in some other of the organic processes of the eye.

We may add that it ceases to be true that coloured pigments and surfaces absorb all the other prismatic components of light, but those tints which they themselves reflect; for, as already shown, there are no prismatic components of light: the prismatic colour is due to the intensity of the vibration conveying the light to the eye, and the effect of the prism in modifying the intensity of that vibration, exclusively. So that when a surface or pigment gives us a blue or red colour it is due, not to absorption of any of the other tints, but to the fact that all light-giving surfaces are reflectors, but reflect with different degrees of vibratory intensity, according to their power to soften the impact and, consequently, the recoil or reflection of light—the blue or red surface or pigment reflecting the whole light falling on it, but with the modified vibratory intensity of blue or red light; and black surfaces still more reducing the vibratory intensity, but never absolutely absorbing the light; though a certain amount of action on the surface or pigment, by absorption of caloric, does take place in the process of softening the impact, and modifying the vibratory energy of the reflection. We might prove this by many experiments which our present opportunities preclude.

Indeed, the idea that coloured surfaces absorbed all the colours of the spectrum, but those which they themselves reflected, never was justifiable even on the old theory, that each colour was elementary, as will appear from the simple facts even then at command. Take, for example, the colours of a spectrum. Is it true that the portion of a surface reflecting the blue tint of the spectrum is absorbing every other tint but the blue? Why, all the other tints are side by side with it, and not one of them falling on the portion of surface which is reflecting the blue; and therefore they are incapable of being absorbed by it. How such a theory ever got into its present general acceptance it is difficult to understand.

SPECTRUM ANALYSIS.

CHAPTER XXX.

Spectroscope adapted to stellar observations by Mr. Huggins—Its explanation of the binary coloured Stars, etc.—Insurmountable obstructions to complete Stellar Spectroscopy—Sudden as well as slow changes in Star Spectra—The star τ Coronæ—Spectra of the Nebulæ—Conclusion that some of the Nebulæ are gaseous(?)—Spectroscopic objections to this conclusion—Special laws of Spectrum Analysis—Questions between the Telescope and Spectroscope—Spectroscopy and the motions of Stars—Means of testing and verifying the spectroscopic conclusions on this subject—Importance of further observations on the Planets and Comets—Specially as to the supposed carbon line in the Comet II of 1868.

So much having been achieved by Kirchhoff in his investigations of the solar spectrum, it was natural that the subject should be followed up by an application of his method, and whatever it suggested, to the spectra of the fixed stars. But here there were peculiar difficulties; Fraunhofer had indeed so early as 1814 pointed out that the spectra of the fixed stars differed from the spectrum of the sun, and so may be said to have opened the way to the achievements of improved and future sidereal optics by a clear announcement of the peculiar interest of the subject.

It was, however, reserved for Mr. Huggins, in conjunction with Dr. W. A. Miller, and also by his individual observations, to grapple with the very great obstacles to be conquered in this direction. And first of all there was one very formidable difficulty which in no way occurred in the investigation of the solar spectrum, and without first overcoming which the whole object was impracticable. A star is but a *point* of light. This point has to be expanded by a line into a vertical band, and kept steadily before a slit of extreme fineness. It is continually changing its apparent position under the earth's diurnal motion, and this mere point of light must therefore be followed and kept strictly under the covering power of the spectroscope. The spectrum of such a body cannot be projected on a screen,* and viewed at leisure. To observe it with anything like competent minuteness and care, a new instrument must be constructed, which at once combines the spectroscope and telescope in one, and the spectrum must be viewed directly in conjunction with that of any element of terrestrial chemistry to be compared with it. The thought and skill which Mr. Huggins has brought to the construction of his instrument have achieved a new triumph in optics, apart altogether from the extremely minute and protracted care and patience of his sidereal investigations themselves. After that triumph was achieved, the labour of investigating each individual star was quite as great as that attending the spectroscopic investigation of the sun; yet Mr. Huggins has investigated since Kirchhoff's discovery the spectra of many stars and comets, and about seventy nebulæ. And, independently, Father Secchi has also at Rome investigated more than 300 stars.

Mr. Huggins and Dr. Miller have found evidence of nine elements in Aldebaran; viz., antimony, bismuth, calcium, hydrogen, iron, magnesium, mercury, sodium, and tellurium: and different elements have been identified in many other stars, some of which we have already mentioned in previous pages.

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* In this particular there is a mechanical defect of arrangement which admits of being overcome. It is sufficient to say to the honour and credit of Mr. Huggins, that he has had to contend against it, and that it has been very embarrassing.

It has also been found that double or binary stars of different colours differ in their spectra, and that the difference is accounted for by the spectroscope. Stars which are blue being found to contain few dark lines in the blue part of the spectrum, and numerous dark lines in the yellow, red, and other tints; while stars red or yellow, etc., contain few or no dark lines in these parts, and many dark lines in other parts of the spectrum. It is perhaps remarkable that these various stars appear so intensely and distinctively yellow, or blue, or red, etc., to our vision, as we have described in a previous place, and that their spectra should, when examined, be found to contain all the tints of the extended spectrum, as well as the one dominant tint manifested by them in the telescope when viewed by it alone; and it confirms one of the laws propounded by us, that the superior distinctness of a particular tint is not always due to its being of the stronger initial energy, or because it is less refracted, but simply because it is sometimes greater in quantity. For instance, were a thousand lights of one size all produced at the same time and at the same combustion point, and one of these was yellow and all the rest blue,—though the yellow light would be the superior in luminosity to any one of the blue lights taken singly, yet it would be probably very inferior in luminosity to the whole nine hundred and ninety-nine lights at any point equidistant from it and them, and so it would be also to the same extent against one blue light nine hundred and ninety-nine times its quantity.

Another fact confirmatory of one of our previous remarks, which we would here take leave to note, is, that while stars of different colours invariably give different and characteristic spectra, and consequently indicate difference of chemical or elementary composition, this is not an absolute or reliable proof that they really do consist of different components; and so far sidereal spectroscopy, though interesting and instructive as far as it goes, is likely to remain permanently and incurably defective. For, as we have already noted in our remarks on coloured stars, to which we again and here specially refer the reader, Sirius seems to have been at one time a red star, and many stars are known to be changing colour. Now, with this fact before us, it is demonstrable, on the evidence of spectrum analysis itself, that Sirius cannot have always given the same spectrum, and it is equally clear that those other stars which are changing colour, cannot; but must in a corresponding degree be changing their spectra also. So that it would require all the different spectra of Sirius from the time of Ptolemy downwards to enable us to judge of only a portion of that star's chemical components; and, even then, our knowledge would be very incomplete, for who can foretell what further changes of colour it may yet undergo? Our remark in a previous place, to the effect that probably no single spectrum could reveal all the elementary components of a star—even assuming that spectrum to be exhaustively complete in itself—is thus fully borne out by the evidence of spectroscopic investigation; and we may therefore hold, as was there indicated by us, that spectra of the same star taken at different times, though found to differ from each other, might ultimately be found to do so without the slightest disparagement to the accuracy of the several observations, and might be found to have their difference attributable to differences taking place in the combustion of the star. We note this the more emphatically, because many conclusions from spectroscopic observation in this department of science are at present, and in the mere inchoate condition of the inquiry, far too positively and absolutely drawn.

The preceding paragraph receives very strong corroboration from the change which took place in the star τ Coronæ, in

May, 1866, which then from a very inconspicuous star, heretofore little noted among its brighter companions in the Northern Crown, suddenly blazed out into a brilliancy equal to that of some of the stars of the first magnitude, and attracted the special attention of spectroscopic astronomy. Mr. Huggins, Dr. Miller, and others made frequent observations of it during its brief brilliancy, and found that instead of its spectrum revealing only dark lines, as usual in solar and stellar spectra, it manifested several luminous bright lines in addition to other dark ones, and particularly two, coinciding with hydrogen, one in the red, and the other in the green,—Fraunhofer's C and F,—and two bright lines in the blue. According to the observations of Mr. Baxendell, the star increased seven hundred and sixty times in brilliancy during the period of its temporary outburst. Father Secchi, M. Rayet, and M. Wolf have observed similar bright bands in other small stars, and γ Cassiopeiæ is a coinciding example. And many stars have been seen to blaze out in a similar manner, which have not been so carefully observed, but which, during the period of their brilliancy, will no doubt in future command more special attention. So that while some periodically variable stars increase in brilliancy so regularly as to leave little doubt that their increase and diminution is attributable to motion, to and from us, in an orbit, others increase and diminish irregularly and unexpectedly, from changes in the condition of their combustion, which can only be ascribed to temporary changes in the arrangements of their chemistry, and the condition and combustion of their gases. And as the bright lines of τ Coronæ disappeared when it returned to its minimum in August, 1866, so may many lines disappear altogether for a time in the spectra of stars when the particular elements are not in a state of gas or combustion, but are in concrete chemical combination for a time beneath the photosphere. It is highly probable that the combustion of τ Coronæ at the period in question was so intensified from some cause as to include the whole hydrogen in its atmosphere in the one blaze, while a portion of it only, at the ordinary temperature of the star, may be incandescent above the photosphere and other portions of the hydrogen below it undergoing combustion *in* the photosphere—the hydrogen thus, in the ordinary case, maintaining a circulation, between the photosphere and chromosphere alternately, under the influence of different temperatures affecting its lightness and density, in which case the presence of hydrogen in the ordinary spectra of τ Coronæ would be revealed by absorption lines.

On examining the planetary nebula in Draco, Mr. Huggins found that it gave no continuous spectrum, but only three bright lines, and he found the same thing of the great nebula in the sword hilt of Orion, and of many of the star clusters which have been long resolved into discrete stars by the telescope. And he appears to us, from hence, to have somewhat prematurely concluded that these nebulæ and star clusters, and also a great many other nebulæ—which he examined and found to give, similarly, only three bright lines, or one or two only of these lines—consist of gaseous matter only, and not of stars. Another class of nebulæ he found gave continuous spectra, and it is somewhat singular that the great nebula in Andromeda, of which we have already made mention, and which may be seen by the naked eye, should be among this latter class, and that greater nearness to us may therefore be suspected as a cause of the distinction. It ought also to be noted, with reference to our further remarks, that the spectrum given by this great nebula is not absolutely continuous, but is blank in the red part, defective in the orange, and marked by mottled imperfections in other portions.

We have said that Mr. Huggins appears to us to have somewhat prematurely concluded that these nebulæ are mere gaseous bodies, on the faith of their spectra of one or more isolated bright lines; and we think a little reflection will make our readers pause before they implicitly accept such a conclusion in the present condition of spectroscopic science, as there are not a few facts of spectrum analysis which appear to conflict with it in such a way as we respectfully think to put it out of court at the present time, from absolute want of evidence in its favour.

In the first place, assuming that these nebulæ are of a gaseous character, it is certain that they are so immensely distant from us, even were they as near as the nearest fixed stars, as to make it impossible they could transmit their luminosity to us if it consisted of stellar or any other conceivable light, first communicated to them, and afterwards *reflected* by them to us. No stars that we can perceive are so situated to them as to be able to give them the light, and we know of no other light external to our own solar system but the "cold light of stars"—certainly no light which could render itself visible to us by reflection from gaseous nebulæ only, and, at the same time, *not* visible to us by any direct incident rays. And, suspected as our gaseous visitants the comets are of sometimes manifesting a slight luminosity of their own in addition to reflected sunlight, we know that the most brilliant comets this world has yet seen would be utterly invisible long before they reached the distance outward of the nearest fixed star. If, then, the nebulæ be gaseous, they must be gases in a very high state of incandescence—much higher than any condition to which we can elevate incandescent gas by any heat within the command of our chemistry. And if they are not so highly incandescent, they cannot be gases, and they could not be visible to us. This is a precise and tangible basis for our logic to begin with. But then, what says the experience of spectroscopy of highly incandescent gases? Why, certainly not that they reveal three bright lines, or one or more bright lines, but that they give continuous and uninterrupted spectra, extending from the red to the violet. Indeed, Dr. Frankland appears to have pretty accurately guessed that this is the condition more especially of the spectra of incandescent gases, and so has entirely anticipated us in the observations and conclusions we have before stated in this respect.

We are now, therefore, at a stage of the subject for further development of its laws; for while it has been indubitably found that incandescent gases give continuous spectra, that is—let the general reader understand—spectra uninterrupted through all the gradations of colour between the red and the violet, it is manifest the prism does not refract the incandescent light of different gases in the same degree, but refracts each incandescent gas in different degree from another; and that even where the spectra of several gases are continuous, the same prismatic arrangement of the spectroscope will not refract them equally. Otherwise it would not be true, as it really is, that,

1. The spectra of two or more incandescent gases overlying each other, when developed from a compound body under combustion or polarization, do not present co-extensive, co-intense, and indistinguishable spectra.

2. The one gas does not produce a spectrum co-extensive with, but inferior in intensity to, and different in the amount o' its refraction from, another; otherwise that of superior intensity would entirely and at all points overlie and supersede the visibility of the others.

[Our explanation of this coincides in the main with Dr. Frankland's conclusion, that the continuous spectra are not due to glowing solid matter, but to the ignition of elementary gases evolved from a compound chemical combination, though our full confirmatory vindication of his views in this respect cannot be here detailed, from the complex nature of the subject, as already indicated, which, as it appears to us at the present moment, would require a separate treatise to itself;

and which we can only in the meantime hope we may soon have an opportunity of devoting to it.]

3. Yet the overlaid spectra do extend through all the tints; otherwise the elements could not give lines in more than one colour.

4. Hydrogen, for example, must develop an overlaid spectrum extending through all the tints, otherwise it could not crop out through an overlying spectrum in the red, blue, and indigo tints at the lines C, F, and G; and it must be more diffused between C and F and between F and G than the dominant spectrum overlying and concealing it intermediately between these respective points or lines, otherwise it could not at each of these reveal a tint greater in intensity than that of the spectrum by which it is overlaid. The apparent reason why this difference of refraction occurs between different incandescent gases is one which we must also in the meanwhile reserve.

5. The same law applies to the general repetition of lines of other elements, such as the numerous lines of iron, etc.; for though it has not yet been found possible to produce all the lines of some elements in bright lines as well as in absorption lines, it is utterly improbable that they *cannot* be so produced.

6. Light from different incandescent bodies, which, when viewed relatively to each other, are of different colours, may, by more highly increased incandescence, give continuous spectra separately, each extending from the red to the violet.

7. Spectra continuous from the red to the violet may very widely differ in their visibility, so that the colours of one spectrum may be present, but latent under circumstances in which another spectrum would be strongly visible and distinct.

It seems, in view of these facts, absolutely impossible to accept the three bright lines given by some of the nebulæ as evidence of a mere gaseous composition, or as a proof that they do not, as heretofore concluded, consist of unresolved aggregations of stars; nor are these the only reasons.

Gases which are *not highly incandescent*, but merely glowing, do within our experience exhibit bright lines, with the intermediate parts of the spectrum dark or nearly so between them; but can this be said to be the condition of gaseous matter so remote as we would in any view be compelled to assume as the nearest distance from which the nebulæ are able *by their own independent luminosity* to reveal themselves to an observer through the optical appliances of our astronomy? It is impossible these gases can be NOT *highly incandescent and yet visible by their own luminosity* at their distance from us. Surely this view of the question disposes of itself so completely as to render it idle to discuss it.

But if we are to assume that we are here dealing with a point in remote space—and doubtless there are such points—beyond which all light of a certain intensity is invisible, and where or near to which consequently all spectroscopic lines, all colour, and all continuosity of the spectrum become wavering and uncertain in their intensity and distinctness, and incapable of being perfectly rendered—why must we assume the gaseous condition as the only one applicable to the imperfect rendering we receive? In a field of view so remote and extended as to be capable of containing a million of stars, it is surely exacting too much to ask us to assume that where three lines only appear in the spectroscope this miserably meagre telegram exhaustively explains all the luminosity embraced within the extended confine. When the Herschel telescope was applied to regions in which that of Earl Rosse has since discovered numerous stars and nebulæ, its report to us was sometimes absolutely nil—should we now be wise if we adhered to its evidence, and rejected the evidence of superior optical power? or would it be wisdom if we held that when the spectroscope was applied in conjunction with the Herschel telescope to such a region, it was right too in rendering to us no report because it could find no spectrum and no bright lines where the telescope had found no light? Should we hold the Rosse telescope thus condemned by a double process for reporting stars and nebulæ in precisely the same region, and put out of court by a balance of evidence? The spectroscope is not a stronger but a weaker instrument than the telescope; for while the telescope enables us to perceive all that is transmitted to us of the luminosity of a distant star, the spectroscope enables us to perceive only a portion of the light of that star, prismatically weakened and reduced; and, much as we respect its achievements within distinct and unmistakable limits, we cannot yet allow it to dominate over the telescope, and dictate to us that star clusters, which are mere nebulosities in weak telescopes, and but feebly perceived to be anything else under such powers as those of the great Herschel instrument, but are clearly resolved into widely separated and discrete stars by telescopes possessed of the space-penetrating power of Earl Rosse's great reflector, are mere nebulous gases, because they reveal only one, two, or three bright lines; and that this is the homogeneous condition of a region so wide, from its obvious telescopic remoteness, that our sun, were he as large in diameter as that of his whole system, with a circumference making each of his meridian lines or great circles equal in dimensions to the orbit of Neptune, would still, if placed there, be reduced by perspective to an inappreciable point, and his luminosity at ten hundredfold its present intensity be utterly invisible. If we get three bright lines, or even one bright line, from such a region in which stars or suns must be more numerous by myriads of millions of times than gaslights in a theatre to give us appreciable light at all, even a single bright line is a large instalment to our knowledge from the wide space area throughout which it shines.

We have found, from what has been before stated, that partially continuous spectra are given by some of the nebulæ, and that, at certain stages between the condition of glowing and highly incandescent gases, partially continuous spectra are developed between the several lines of the glowing gas in course of progress to the full continuous spectrum given by the highly incandescent condition of the same gas; and these partially continuous spectra are therefore so obviously an abortive attempt to give full spectra under the disadvantage of mere feebleness of luminous power, that we may well hesitate before accepting, as a gratuitous assumption, that the spectra of the nebulæ are full reports of their chemical condition, or that still decreasing luminous power does not in every case come down to a few lines without continuous spectra; and, as a *dernier ressort*, before parting company with our optics in regions so remote, waves its light signal of departure to us at the very minimum point in the tenuity and visibility of a single bright line.

These facts of spectrum analysis, therefore, are too uncertain to justify strong conclusions against the evidence of the telescope as to the substance and the composition of the nebulæ, or the account we have before given of them on the high authority of that instrument. We gladly and heartily thank the assiduous labourers in the fields of sidereal spectroscopy for their instalments to our knowledge, and willingly acknowledge the high merits of their achievements; but we cannot recognize these instalments as the full debt due to knowledge, or as a sufficiently comprehensive state of information to justify us in proceeding to judgment. The interests and the very character of science require that we should not incur in its name the censure pronounced under the highest authority on him who judgeth a matter before hearing it, and we therefore in the meanwhile reserve our decision.

On the subject of the motions of the fixed stars, and the powers of the spectroscope to discern and decide on these in the nearer fields of space, we will now call the reader's attention to some of the circumstances. At an early stage of the work we mentioned the conclusions come to concurrently but independently by Mr. Huggins and Padre Secchi, in reference to Sirius more particularly, which they found to be passing outward from us at the rate of twenty-nine miles per second. From what we have stated of the laws of different kinds of light in the preceding chapter, and their different velocities, there will appear *new* reasons for believing that a difference in the velocity of the light from a body receding from us or approaching more nearly to us at the rate of twenty-nine miles per second, ought to give some evidence of itself in the spectrum of the object, and a peculiarity has been discovered by these eminent spectroscopists to exist in the spectrum of Sirius and of other stars known to have proper motions, which does not appear accountable in any other way. Taking Fizeau's statement of the velocity of light at 194,000 miles per second, it must be apparent that the rate of twenty-nine miles per second of diminution on this velocity, only a 6,700th part of the whole, must be a very minute quantity for the spectroscope to deal with; and it shows the micrometrical care which has been applied in the investigation, when we find two observers coming separately to so precise a conclusion on the subject.

The progress of light, whatever it be in free space, is, as already mentioned, accomplished by means of undulations or vibrations, analogous to those of sound, through atmospheric or other impeding media. How these vibrations in free space can take place, any more than vibrations from a bell in a vacuum, it is difficult to conceive; but of the vibrations in impeding, but still transmitting media there is no manner of doubt, nor, perhaps, as to the fact that the radiation of a body receding from us in the regions of free space would impinge with less force on the exterior boundary of our atmosphere than if it were travelling toward us—even were we to assume that the light traversed free space instantaneously, just as a solid body pushed by one end is at the other extremity of it instantaneously moved forward in the direction of the impulse—for even then we know that a solid body may be pushed with greater or less rapidity. The undulations of such radiance would therefore be more or less intense in our atmosphere, just as the undulations of advancing or receding sound would be; and the peculiarity found by Mr. Huggins in the spectrum of Sirius, taking Fraunhofer's F line (the bluish-green hydrogen line) as the criterion, is that a deviation takes place in the line, which, when compared with that of the solar spectrum and the deviation which takes place in the same line between the spectrum of hydrogen in vacuuo and hydrogen at atmospheric pressure, indicates a diminution of the impulse of the light of Sirius, with reference to that line, equivalent to a want of velocity in the light to the extent of twenty-nine miles per second.

The subject is of very great interest; and while the conclusion come to appears to be only the most intelligible interpretation of a peculiarity which does exist, and which does require explanation, it would still be desirable, by more extended observation and crucial testing, to give it all the confirmation in our power. For example, we have *certain* knowledge that many of the planets of our system *do*, between certain parts of their orbits in which they approach us, and other parts of their orbits when they recede from us, make a difference of motion, putting their advance and recession together, of more than twenty-nine miles per second; and we also know that the laws of their spectra are, with few exceptions, identical with those of the sun. If the same deviation in character, and in proportionate degree, be found to exist in all the identifiable lines of the planets under these circumstances, and to correspond in all respects with the independently ascertained velocity of their motions, we shall then have such a confirmation of this conclusion with regard to Sirius, as will render it absolutely irrefragable.

The comets appear to present another series of bodies in motion, which are so far fitted for the same testing; for though we cannot identify their lines with those of the solar or other known spectra, except, perhaps, in the case of carbon, recently identified by Mr. Huggins, yet we can compare their spectra at different points of their orbits round the sun—those when they are approaching us or receding from us most rapidly, and those at which they are comparatively stationary to us—and, collating these spectra with each other, see what difference, if any, there is; and what *can* be, as compared with what *ought* to be, attributed to motion. No doubt comets are not the most reliable of bodies even for such a purpose as this; for they cannot be expected to give very uniform spectra at all, as the difference between their condition at points of their orbit where they are remote from the sun, and at other points where they are, from proximity to that luminary, incandescent with his heat, must affect their chemical condition and spectra to some degree, and call for more special observation. It might be of great value also, in testing the accuracy of cometary spectroscopy, when such another opportunity occurs as Mr. Huggins found of observing the carbon spectrum in Comet II of 1868, if the discovery were followed up by a series of observations to asertain whether in approaching to, and incurring incandescence from, the sun, and receding from him again, the lines of the spectra complied with the laws of increased or diminished heat, which the true carbon spectrum would exhibit under similar circumstances. We make this suggestion with special reference to our remarks when treating of the comets, as to their chemistry not complying with known chemical laws.

PART IV.

ASTRONOMICAL DISTANCES AND LAWS, ETC.

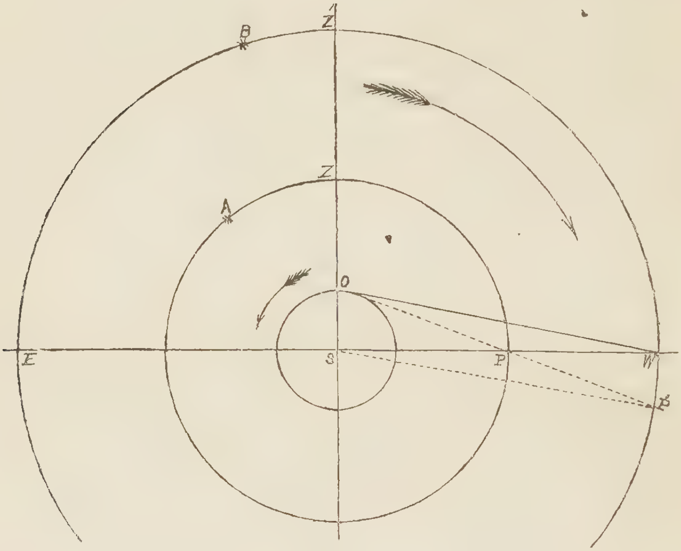
CHAPTER XXXI.

Parallax—Importance of the diurnal and annual revolutions of the Earth—Parallax generally—Parallax as perceived in railway travelling, etc.—Application of this to diurnal parallax—Limits of diurnal parallax—Increasing difficulties of parallax—Objects beyond diurnal parallax—Annual parallax, and objects beyond it—Data for estimating distance of objects beyond all parallax—Distance of the Nebulæ—Distance of the Nebula 97 M Ursæ Majoris—Mathematical difficulties and triumphs—M. Le Verrier and Mr. Adams from a popular point of view.

The general reader is naturally anxious to know something of the means by which the mensuration of astronomical distances is acomplished, as far as he may be able to understand them, without going into those abstruse and consecutive problems of mathematics which would occupy to him the leisure of a lifetime to investigate, were he to become a thorough mathematician like any of the eminent men who now occupy the front ranks of this branch of science. We will therefore—omitting all minute and technical details—endeavour to render intelligible and simple all that is necessary for him to know to enable him to form a fair rational judgment of the substantial means of fixing the distances at which heavenly bodies are situated, by illustrating the meaning and application of what is called parallax.

All bodies external to this world change their apparent positions with reference to an observer situated on the earth's surface, from two causes: *first*, the daily rotation of the earth on its axis, and, *secondly*, the annual revolution of the earth in its orbit. The first of these causes we will deal with in the first instance. From this cause, by the rotation of the earth on its axis in twenty-four hours, the sun, at a distance of 91,000,000 miles, and the moon, at a distance of 238,000 miles from the earth, *appear* to perform revolutions round our world in precisely the same time, viz., twenty-four hours each; and were this real, instead of merely apparent, the consequence would be that the sun would travel in the same period of time somewhere about four hundred times further than the moon. This is, relatively, the same with regard to all the fixed stars; for were we still to hold with some of the ancient astronomers, and with the Pope and College of Cardinals in Galileo's time, that the earth is fixed, and does not go round, then we should have this extraordinary problem of astronomy to account for, namely, why every planet and satellite and comet, as well as the sun and every star in the whole heavens, moved round this world—and all in exactly the same time, however remote or near they happened to be! and also why bodies like the planets, changing their distances from us to extents equal to the major axis or longest diameter of their orbits, should still at all points of their increasing or diminishing distance continue to pass round the earth in the same apparent period of twenty-four hours. And were such a circumstance real, it may be safely said we should never be able to assign any reason for it, or give any explanation of it, except by simply relating the arbitrary fact that it was so. But the diurnal rotation of the earth on its axis furnishes us with a perfect explanation of the reason why this *appears to be so*, and why, in reality *it is not so*. This will be more apparent from the explanation of diurnal parallax.

Parallax, generally, is the difference between the *apparent* place of an object with reference to the point of observation, where that point is a movable point, and the *real* place of the object with reference to the central point round which the movable point of observation circulates. Thus every point of observation on the surface of this world, except the two polar points of the earth's surface, move or circulate round the axis of the earth; and the diurnal parallax of a celestial object is the difference between the apparent place of the object, so viewed, from a movable point on the earth's surface revolving round its axis, and the real place of the object with reference to the axis of the earth, or to the centre of the earth and of its axis. Thus let the small circle in the diagram (p. 360) represent the earth, with S its centre, and O a point on its surface, at which the terrestrial observer is situated, and the line E S W represent a line running from east to west through the earth's centre. This line will evidently bisect the diurnal motion of the observer at O round the earth, because he passes every terrestrial day round the axis of the earth in the direction of the small arrow from west to east; but, instead of being conscious of this his own real motion with reference to fixed objects external to the world, and that he is hurrying onward, from west to east at the rate of a thousand miles or so per hour beneath the stars, on his whirling vehicle the earth, he will be rather impressed with the perception, apparent to his eye, that bodies external to the earth at the points A and B, or the sun, moon, planets, and stars, are hurrying past him, and describing a reverse path over him from east to west, in the direction of the large and reverse arrow, just as a person in a railway train is much more sensible that trees, buildings and rocks, or other fixed objects, are apparently hurrying past him, while he is in reality hurrying past them at forty or fifty miles per hour. But, as in the railway train, we find that near objects dash much more hurriedly past the window of the carriage than the more distant objects of the landscape, so is it true of more distant objects in the sideral heavens, as compared with nearer objects—although this is not quite so manifest to careless observation, from the fact that there are no very near celestial objects, and that the difference between the rates of apparent speed of such objects is not so conspicuous. But as the reader will be perfectly able to remember, from his experience of railway travelling, that a distant object never appears to pass him more rapidly or so rapidly as a nearer object, so he has here in his own possession and experience a fixed and



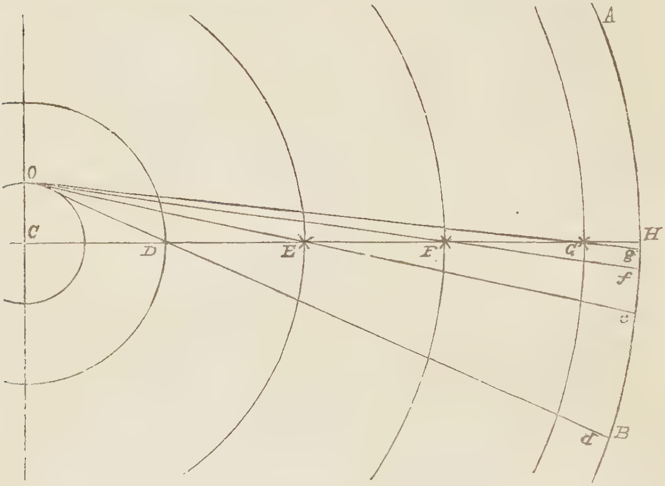
perfectly reliable law, which may be enunciated in the following terms:—

A person travelling at a given speed past fixed objects will find that they appear to pass him at a speed proportioned to their respective distances from him, and that the comparative rapidity with which they pass him is an absolute criterion or means of finding their respective distances.

Let us now apply this law to our diagram just given, and see how it becomes more clearly intelligible and absolutely demonstrable thereby. Objects at the distance of A and B from the observer situated at O will appear to revolve round or pass the observer in the direction of the large arrow; but in the time which the more distant body B requires to pass from its zenith or culminating point Z to W, the nearer body A will pass from Z to P, and, as it will appear to the observer, in the line of his vision O P P′ it will *appear* to have surpassed the more distant body B in speed in the same time by the difference between W and P′. In other words, the body A in describing a quarter of its apparent diurnal motion round the earth, will appear to the observer to have travelled the distance from Z to P′ in the time taken by the more distant body to describe a quarter of its apparent diurnal motion round the earth from Z′ to W. But as the astronomical observer is perfectly certain, from the law already announced, that the more rapid body is the nearer one, he is quite able, from the apparent difference of their speed, to make his calculation that, dividing the day into four parts, the nearer body A takes in reality just exactly a quarter of a day to pass from Z to P′, or a fourth part of its daily circuit round the earth; and that the more distant body, in like manner, takes just the same time, namely, a quarter of a day, to pass from Z′ to W, a fourth of its daily circuit round the earth; and that consequently, their apparent diurnal motions being divided into one-fourth part by the culminating line S O Z Z′, and a line passing through the centre of the earth E S P W, the real position of the nearer object A, when it is in the line of vision O P P′, is not at P′, but at P, and that its angle of distance, measured by triangulation, is not O S P′ but O S P; and that the distance between W and P′ is only its parallax, and not an indication of real position; and in like manner he also knows that the true distance of the object B when at W, measured by triangulation, is O S W. These facts being thus ascertained, the basis of the calculation of distance is within the grasp of the mathematician; for, as will be found sufficiently demonstrated in elementary geometry, one of the sides and two of the angles of a triangle being known, the other sides and angles may be discovered therefrom. Here one of the sides of the triangle O S, is the radius or semi-diameter of the earth, and two of the angles are also known; for the angle at S is always a right angle, and the angle at O is indicated to the astronomer on his graduated circle; so that from these elements, by a clear and precisely fixed formula, the other elements of the triangle can with certainty be deduced; and, consequently, among them the side S P of the triangle O S P and the side S W of the triangle O S W.

In taking the earth, and parallax as developed by its diurnal motion, as our standard of measurement, it will be obvious to the general reader that we are dealing with a basis of measurement in the one known side of the triangle of no more than 4,000 miles in extent, the radius of the earth, and that the other sides of the triangle will be proportionals to that dimension. But if in the diagram to which we have been referring we take the smaller circle as representing, not the earth's circumference, but the earth's orbit, then the one known side of the triangle will be the semi-diameter of that orbit, or ninety-one millions of miles,—an increase of our basis of measurement, which should enable us to increase our powers of mensuration to objects twenty-three thousand times further removed from us than those capable of being ascertained by diurnal parallax. If we *assume* the extreme distance of the planet Neptune as the body most remote from us capable of being measured by diurnal parallax, or a distance of 2,770,217,344 miles, we should, by annual parallax, be able to ascertain the distance of objects 62,000,000,000,000 miles away: but this is evidently within the limit; for Peters has given us the distance of Capella as 408,000,000,000,000 miles, or more than six times as far as the above assumption of the limit of annual parallax; so that we may conclude, on that basis alone; that diurnal parallax is capable of enabling us to measure the distances of planets greatly more distant than Neptune, should such planets be still found as members of our system.

As bodies increase in distance, parallax becomes increasingly difficult to detect, as will be seen from the following diagram (p. 364), in which we present four bodies, D E F G at different distances, the second being twice, the third three times, and the fourth four times as distant as the first from the centre of measurement C. Here the parallax is delineated on a background equidistant from C, but beyond the remotest of the objects, and represented by the partially delineated circle A H B, from which it will be seen that the parallax of D, the nearest object to C, is H *d*; that of E, the second object from C, is H *e*; that of F is H *f*; and that of the fourth and more distant object, although only four times more distant than the nearest, is the almost inappreciable parallax H *g*. This result is correspondingly felt to operate on the angle at O, where the observer is situated and applying his delicate micrometrical arrangements in measuring the special angularity there, which is the only unknown quantity he requires to ascertain to enable him to determine the respective distances of the objects; for, to him, the graduated portion of a circle he applies to determine that amount of angularity is practically, as a means of comparison between the four objects and their parallax, the circle A H B in miniature. It is in fact, to him, the detector of the amount of parallax of each object. He already knows the one side of his triangulation O C, and he also knows that the angle at C is a right angle; about this he has no dubiety; but the angle at O he has to make perfectly sure of, for upon his precision there, depends the accuracy of his whole calculation. It will be apparent, however, to the reader, that as objects increase in distance the angle at O has a proportionately greater tendency to approximate to a right angle like the angle at C, and the line of vision from O to the object to become more nearly parallel to the line C D E F G H. And this is so much the case that all the fixed stars present no diurnal parallax, and the angle at O given by them is not to the minutest measurement distinguishable from a right angle. It requires the annual



parallax furnished by the greater base of the earth's orbit to enable us to detect parallax in the position of the nearest fixed stars, and stars of lesser magnitude will probably never exhibit parallax even with that extended base of mensuration. Indeed, the stars which do exhibit parallax, exhibit it in so minute a degree that, taking all the complications into account, and all the qualifying circumstances which require to be eliminated from the calculation, a doubt still hangs over the parallax detected, which may yet be found to make their distances, if not absolutely immeasurable, at all events much greater than that assigned them by the present calculations. Their distances, it is quite certain, cannot be *less* than that stated, so that for all purposes our estimates have been on the safe or minimum side.

But having arrived at these conclusions, and admitting the great difficulties involved, the reader will naturally inquire how comes it that we have ventured so freely to deal with distances so much greater than that assigned to the furthest ascertained distance of any fixed star, and on what criteria and bases of mensuration have we proceeded so vastly beyond the range of all definite or possible parallax? This inquiry is just, and we will have much pleasure in answering it, and enabling the reader by an extremely simple process to satisfy himself; for the criteria we have adopted are, on the basis of all known analogy, legitimate and reasonable, and the only known guides in the absence of positive knowledge or certainty; otherwise we would not have ventured to use them.

We have said, on the basis of ascertainable parallax, in a previous portion of the present work (p. 66), that the mean distance of Sirius and Capella, both stars of the first magnitude, and whose maximum parallax has been ascertained, is about 278,203,000,000,000 miles. In penetrating the Galaxy with his great telescope, Sir William Herschel, as there stated, considered he had penetrated depths of space 2,300 times the mean distance of first-magnitude stars; consequently we have here, on definite data . 278,203,000,000,000 miles,

Multiplied by 2,300

Or equal to . . . 639,866,900,000,000,000

as the extent to which Sir William was able to penetrate the Galaxy in one direction from our interior position, without being able to pass through it into the dark background beyond. This distance, assuming that we are situated in the centre, would represent the semi-diameter or radius of the galactic ring. But how from this basis did we come to the conclusion that the distance of one of the largest or nearest of the planetary nebulæ, 97 M Ursæ Majoris, is at least 1,580,000,000,000,000,000,000 miles? The mode by which such a conclusion is arrived at is simple enough.

In the first place, let us explain that, for astronomical purposes, every circle is divided into three hundred and sixty degrees (360°), each degree into sixty minutes (60′), and each minute into sixty seconds (60″).

A circle therefore consists of . .	360°
or 360° × 60′ = ...	21,600′
or 21,600′ × 60″ = . . .	1,296,000″

And this is the astronomical subdivision of every circle, large or small. Consequently a degree or 360th part of a small circle is a very different quantity in point of dimension from a degree or 360th part of a large circle; yet for the practical purposes of astronomical science, this subdivision is found to be quite convenient for the purposes of mensuration, as will be perceived by the application of it to the question we are now called on to answer, namely, the comparative distance of the planetary nebula 97 M Ursæ Majoris, basing our estimate on the semi-diameter of our own Galaxy, given above. This planetary nebula, as we have explained in our chapter on these singular stellar arrangements, is in all respects as complicated a star system as that of our own Galaxy, and, we may reasonably conclude, is at least of the same dimensions. Its apparent diameter is found to be, as before stated, 2′ 40″; that is, if a circle with our position as its centre, and the distance, whatever it may be, of 97 M Ursæ Majoris for a point on its circumference, were drawn through 97 M Ursæ Majoris, the diameter of 97 M Ursæ Majoris would form two minutes and forty seconds of the whole of that circle of 360°. The question, therefore, is to ascertain what are the dimensions of such a circle; for then we should be able to deduce from that what the radius of the circle amounts to, as that is identical with the distance of the nebula from us. Now we have the means of ascertaining what the dimensions of the circle are by assuming the nebula to be equal in diameter to our own Galaxy; for then 2′ 40″ of such a circle must be equal to about 1,370,000,000,000,000 miles; and as there are 1,296,000″ in a circle, as before explained, and as 2′ 40″ are equal to 160″, or the 8,100th part of a circle, it thence follows that there are 8,100 times the above number of miles, or of the diameter of our galaxy, in the circumference of a circle whose radius, as before stated, is the distance from our world of the nebula 97 M Ursæ Majoris; and taking the radius of a circle roughly at about equal to the seventh part of its circumference, we should have by calculation upwards of 1,580,000,000,000,000,000 as the radius of the circle, or the distance of the nebula.

To simplify the matter still further to the general reader, the calculation and data in detail are as follows :—

The diameter of the nebula is assumed by reasonable analogy

to be equal to that of the Galaxy; therefore, the apparent diameter of the nebula being 2′ 40″, it follows that 2′ 40″ is equal to . . . 1,370,000,000,000,000,000,000
the diameter of the Galaxy in miles.

But 2′ 40″ is equal to 160″, or the 8,100th part of a circle, because 160 × 8,100=1,296,000, the number of seconds in a circle, as above. Hence, the diameter of the Galaxy, multiplied by . 8,100
gives for the number of miles in the circumference of the entire circle a result of . . . 11,097,000,000,000,000,000,000
And the radius of a circle being assumed at the 7th part of its circumference, the above sum when divided by 7)
will give upwards of . 1,580,000,000,000,000,000,000
the number of miles in the radius, or the distance in miles of the nebula.

Of course, as we have been careful to say, it is mere matter of assumption on the basis of analogy that this nebula is equal in diameter to the Galaxy, and the accuracy of that assumption lies at the root of the calculation. But the question is whether this assumption be a fair one, and whether the analogy on which it is founded be not the only element at our command in approximating the question, and whether in addition to this it is not a perfectly reasonable and highly probable analogy. We have set forth the circumstances impartially in these pages, and must leave the reader to judge for himself.

There is another but inferior element of uncertainty in such calculations indicated in what we have stated as the assumed proportion of the radius of a circle to its circumference. But though this apparently simple question of plane geometry has not yet been solved, the proportion can be approximated sufficiently for all practical purposes, to leave us in no serious difficulty about the truth being within a very narrow limit one way or other. And in referring to the achievements of astronomy, notwithstanding this defect in elementary geometry, and the perfect certainty with which orbitual revolutions are calculated, and eclipses, transits, and occultations foretold, it must be manifest that this is no serious impediment to the practical astronomer even in penetrating great questions with the minutest accuracy. When we find his calculations so complete, that, with the most limited data to guide him, he can tell with certainty where a disturbing cause is to be found at a particular moment in the form of a new planet never known or heard of before, as in the triumphant discovery of Neptune, we cannot admire too much the immense patience and precision and skill by which the geometrician is enabled to conquer the difficulties of his science, and give us results so brilliant. Indeed, with special reference to the magnificent achievement just mentioned, we feel so much indebted both to M. Le Verrier and Mr. Adams, that we could scarcely wish their laurels to rest otherwise than as they do, because the double calculation of the new planet so made by them enables us to satisfy the general reader when we should perhaps fail to do so by a more complex or mathematical process, that the discovery of this new planet was not a mere successful guess of one singularly fortunate mind, but was approached by an accurate and logical process, which totally independent thinkers could take up and follow out with a perfectly certain and unerring precision to a definite and inevitable result. It seems to us to have required for the popular mind that this wonderful discovery should be confirmed by two independent calculators, to satisfy the non-mathematical reader that the triumph was one not of mere good luck, but of pre-eminent ability and skill, and that in this respect the distinguished calculators are not rivals, but vindicators of each other; and in that light we certainly prefer to regard them.

ASTRONOMICAL DISTANCES AND LAWS, ETC.

CHAPTER XXXII.

Labours of Mathematicians—Of Kepler—His investigation of Circular Orbits—His discovery that Orbits are not circular—His investigation of the Ellipse—His discovery of the true curves of Orbits—His investigation of planetary relations—His first great law—His further researches—His second law—Renewed investigation—Labour and disappointment—Return to the subject, and final triumph and gratitude—His third law—Popular explanation of his laws—Kepler and Laplace.

Of course, in the preceding rough sketch of the general principle involved in the mensuration of astronomical distances, intended purely for the comprehension of the general reader, we have given little or no indication of that complex system of calculations on which planetary motions, attractions, and perturbations, such as those involved in the discovery of Neptune depend. To go into such questions requires that the leisure of the general reader should be devoted to labour instead of to relaxation and ease; that he should be prepared to become a profound mathematician at once, and to begin in right earnest at the beginning of his work; for it is not possible to pass him through a course of mathematics in a few sentences, and even genius can make no royal road to learning here. The achievements of geometry and algebra are essentially those of patient industry and time, even when treated with the most masterly skill, and few who have not faced the first difficulties of these sciences with the necessary determination can tell how frequently and long the most skilful of mathematicians have laboured in vain, and how often a trivial error, in complex and multitudinous calculations, has sickened the heart, and delayed or defeated success, and taught the disappointed aspirant for intellectual achievements how bitterly and truly much study is a weariness of the flesh.

Let the following eloquent description of Kepler's labours and triumphs suffice to convince the general reader on this subject, and at the same time commend to attention a volume * worthy of a place in the library of every lover of scientific truth :—

" Copernicus had merely commenced the examination of his bold conjecture. A lifetime was too short to accomplish more. He had transferred the centre of motion from the earth to the sun, and rested the truth of his hypothesis on a *diminished* complexity in the celestial phenomena. In case the true centre had been found, it now remained to determine the exact curves in which the planets revolved, the laws regulating their motion, and the nature of the bond which it was now suspected united the planetary worlds into one great system. The resolution of these profound questions was reserved for *Kepler*, who has, without flattery, been termed the Legislator of the heavens, and who has earned the reputation of being *first* in fact and first in genius among modern astronomers. He united, in the most perfect manner, all the qualifications of a great discoverer. Ardent, enthusiastic, and subtle, he pursued his investigations with a keen and restless activity. Patient, laborious, and determined, difficulties shrunk at his approach, and obstacles melted before him. Unprejudiced and pious, he sought for truth in the name and invoking ever the guidance of the great Author of truth. If his theories were not actually deduced from facts, when formed, no test was too severe, and nothing short of a rigid coincidence with fact could satisfy the exacting mind of this wonderful genius. Realizing fully the difficulty and importance of the researches before him, once commenced, his perseverance knew no limit, and the fertility of his imagination was utterly inexhaustible.

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* "The Orbs of Heaven," by O. M. Mitchell, conclusion of Lecture III.

"Such was the man to whom the interests of science at this critical juncture were committed. Having adopted as an hypothesis the central position of the sun, and the revolution of the earth and planets around this centre, he determined to discover the true nature of the planetary orbits, and find, if possible, some single curve which would explain the orbitual motions of the celestial bodies. To accomplish this difficult enterprise, Kepler wisely determined to confine his efforts and investigations to one single planet, and Mars was selected as the subject for experiment. He commenced by a rigorous comparison between the observed places of the planet, and those given by the best tables which could be computed by the circular theory. Sometimes the predicated and observed places agreed well with each other, and hope whispered that the true theory had been found ; but pursuing the planet onward in its sweep around the sun, it would begin to diverge from its theoretic track, its distance would increase, until it became evident that the theory was false, and must be abandoned.

"Nothing daunted, the ardent philosopher consoled himself with the thought, that among all possible theories which the mind could frame, one had been stricken from the list, and a diminished number remained for examination. This was a new mode of research ; and in case the number of theories was not too great, and the patience of the philosopher sufficiently enduring, a time would come, sooner or later, when success must reward his labours. Thus did Kepler toil on, subjecting one hypothesis after another to the ordeal of rigid experiment, until no less than nineteen had been tested with the utmost severity, and all were rejected. Eight years of incessant labour had been devoted to this examination. He had exhausted every combination of circular motion which the fertility of his imagination could suggest. They had all utterly failed. The charm was ended, and he finally broke away from the fascination of this beautiful curve, which for five thousand years had so bewildered the human mind, and boldly pronounced it impossible to explain the planetary motions with *any* circular hypothesis. This, at least, was a great negative triumph. If he had not found the curve in which the planets revolved, he had found what it could *not* be; and, released from all future embarrassment from eccentrics and epicycles, he now pursued a lofty and independent train of investigation.

"Leaving for ever the circle, the next simplest curve is called the ellipse, an oval figure, which, when but little flattened, very nearly resembles the circle in form, but enjoys very different properties. All diameters of a circle are equal. The diameters of an ellipse are unequal. The centre of the circle is equally distant from all points on the circumference. No such point exists in the ellipse; but two curious points are found on its longest diameter, possessing the remarkable property of having the sum of the lines joining them with any point of the curve constantly equal to the longest diameter. Each of these points is called a *focus*. This beautiful curve, with its singular properties, had been discovered by the Greek mathematicians; but not remarking its use in nature, it had hitherto been regarded only as an object of amusing speculation. To this curve did Kepler apply, when driven from the circular hypothesis, and again commenced his system of forming hypotheses, and hunting them down, as he termed his scrutinizing process. As in the circular hypothesis, the sun had at first been located in the centre, so, in commencing the elliptic theory, the centre of the longest diameter was made the centre of motion. Buoyant with hope, the astronomer sets out to follow the planet around its elliptic orbit; but although for a short distance its movements were well represented, it finally broke away from the elliptic track, and bid defiance to the central hypothesis. But Kepler was not in the least disheartened with this first effort. He now shifts the sun to the focus of the ellipse, constructs his orbit, starts once more on the track of the planet, watches it as it sweeps onward around the sun; the elliptic orbit holds it as it moves, farther, and still farther. Half its revolution is performed, and there is no diverging; onward it flies, the goal is won. Triumph crowns the philosopher, *the orbit is found!*

"Thus was accomplished one of the most important discoveries which the mind had ever reached. The elliptic orbit of Mars rapidly led to those of the other planets, and to that of the moon, and Kepler proclaimed to the world his first great law, in the following language: '*Planets revolve in elliptic orbits about the sun, which occupies the common focus of all these orbits.*'

"This law swept for ever from the heavens and from astronomy those complications which had stood the test of centuries, nay, of thousands of years. Their mysterious power was paralyzed by this single touch of the enchanter's wand, and they fled from the skies. The circle was as simple and beautiful as ever; but its divine character was gone, and the gods or angels who had so long held their abodes in the planets were exiled from their homes. The dawn of *modern* science broke in beauty on the world.

"Kepler having been so signally rewarded by this great discovery, now turned his attention to an investigation of the first importance,—one, indeed, which was indispensably necessary to render his first discovery available. As the planets were known to revolve in ellipses, and as their motion was found by observation to be unequal in different parts of their orbits, it became a matter of the first consequence to ascertain some simple law regulating the orbitual motion, and by means of which a planet might be readily followed, and its places computed. To detect this law, in whose existence Kepler seems to have entertained the most unwavering faith, a figure was drawn representing the orbit of Mars, the sun occupying one of the foci of the curve. On the circumference of this curve the places of the planets were marked down as observation had determined them; and here commenced a series of examinations which finally led to the knowledge of the second great law of the planetary motions, which may be thus announced: *If a line be drawn from the centre of the sun to any planet, this line, as it is carried forward by the planet, will sweep over equal areas in equal portions of time.* This law accorded in the most perfect manner with fact, and gave at once the power of following, and, from the mean motion, computing the place of any planet,—a triumph which all the complexity of older systems had failed ever to accomplish.

"Any other mind less adventurous than that of Kepler might have been satisfied with these two great discoveries. The precise curves described by the planets, and a law regulating their motions in their orbits, sufficed to render all the phenomena of the heavenly bodies not only explicable, but susceptible of accurate prediction. There seemed nothing more to be added. Kepler did not think so. He conceived the idea that the solar system was not a mere assemblage of isolated planets revolving about a common centre, but a great associated system, in which some common bond of union existed, which, once found, would present the solar system in a new and true light.

"This bond he believed existed in some hidden relation between the times occupied by the planets in describing their orbits, and their distances from the sun. In the history of this remarkable research, we are presented with one of the brightest examples of the fruits of perseverance. If some superior power, some spirit from a brighter world, had revealed to the mind of Kepler the actual existence of some relation between the planet's periods and distances, and had proposed to him to discover this hidden law, there would have been a definite object before the astronomer, and to have persevered in the pursuit of this object would have been within the limits of probability, even if a lifetime were exhausted in fruitless efforts. But to excite in his own mind a faith sufficiently strong in the existence of a law of which there existed not the slightest evidence, and to have persevered in its research for seventeen long years of laborious effort, seems almost incredible.

"There is an immense difference between the pursuit which resulted in the discovery of the first two laws of Kepler, and the third one. In seeking for the curve described by the planets, it was looking for that which must have an existence; and in tracing the law of a planet's motion, it was absolutely impossible to follow a planet, or predict its positions, without such a law. But in seeking for a bond of union among the planetary periods and distances, it was a search for that which, it was believed, had no existence, except in the wild imagination of this extraordinary philosopher. The history of mind scarcely furnishes an example in any degree parallel, if we except, perhaps, the heroic fortitude which marked the career of Columbus. Yet even the great Genoese was in possession of solid facts on which to base his reasoning. He saw evidences of the existence of another hemisphere, which the superficial could never realize. Kepler, more bold, more grand, more sublime, dreamed of nothing less than a brotherhood of worlds, a mighty and magnificent scheme of vast revolving orbs. Should success crown his efforts, the most brilliant results would follow. The distance of a single planet from the sun once obtained, and the periodic time of all being known, the distances might then be found for each individual in the entire system, without even directing an instrument to the heavens. Here then was a prize, to reach which no time, or pains, or labour could be misapplied. Its return would be a hundredfold.

"But where was the prize to be sought? Even admitting that some common bond did bind the circling worlds into one harmonious system, did it exist in some hidden relation between their periods of revolutions, their distances, their magnitudes, their densities? or was it to be sought in some analogy between the distances and periodic times? After long and deliberately pondering this great problem, Kepler decided that the strongest probability suggested that the distances of the planets, and their periods of revolution, would in some way contain the mysterious bond of union. Here then did this daring mind concentrate its energies; and his purpose once fixed, he marches steadily forward in his research with a courage which no defeat could daunt, and a perseverance which knew no limit but success.

"Before announcing the final result, let me explain two terms employed in its statement. The *square* of any quantity results by multiplying it by itself. The *cube* comes from multiplying the *square* by the number. The square of a planet's period, or the cube of its distance, are known the moment we know the period and distance, by applying the simple rules of arithmetic. After Kepler had exhausted all simple relations between the periods and distances of the planets, in no degree shaken in his lofty faith, he proceeded to try all possible relations between the squares of the periods and distances, but with as little success. Nothing daunted, he proceeded to investigate the possible relations between the cubes of the periods and distances. Here again he was foiled; no law exhibited itself. He returned ever fresh to the attack, and now commenced a series of trials involving the relations between the simple periods and the squares of the distances. Here a ray of hope broke in upon his dim and darkened path.

"No actual relation existed, yet there was a very distant approximation, enough to excite hope. He then tried simple multiples of the periods and the squares of the distances: all in vain. He finally abandoned the simple periods and distances, and rose to an examination of the relations between the squares of these same quantities. Gaining nothing here, he rose still higher, to the cubes of the periods and distances; no success: until, finally, he tried the proportion existing between the squares of the periods in which the planets perform their revolutions and the cubes of their distances from the sun. Here was the grand secret; but, alas! in making his numerical computations, an error in the work vitiated the results, and with the greatest discovery which the mind ever achieved in his very grasp, the heart-sick and toil-worn philosopher turned away almost in despair from his endless research.

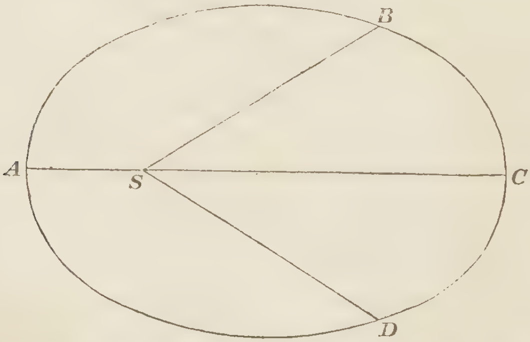
"Months rolled round, and yet his mind, with a sort of keen instinct, would recur again and again to this last hypothesis. Guided by some kind angel or spirit, whose sympathy had been touched by the unwearied zeal of the mortal, he returned to his former computations, and with a heaving breast and throbbing heart he detects the numerical error in his work, and commences anew. The square of Jupiter's period is to the square of Saturn's period as the cube of

Jupiter's distance is to some fourth term, which Kepler hoped and prayed might prove to be the cube of Saturn's distance. With trembling hand he sweeps through the maze of figures; the fourth term is obtained; he compares it with the cube of Saturn's distance. They are the same! He could scarcely believe his own senses. He feared some demon mocked him. He ran over the work again and again; he tried the proportion, the square of Jupiter's period to the square of Mars' period as the cube of Jupiter's distance to a fourth term, which he found to be the cube of the distance of Mars; till finally full conviction burst upon his mind: he had won the goal, the struggle of seventeen long years was ended, God was vindicated, and the philosopher, in the wild excitement of his glorious triumph, exclaims:

"'Nothing holds me. I will indulge my sacred fury! If you forgive me, I rejoice; if you are angry, I can bear it. The die is cast. The book is written, to be read either now, or by posterity, I care not which. It may well wait a century for a reader, since God has waited six thousand years for an observer!'

"More than two hundred years have rolled away since Kepler announced his great discoveries. Science has marched forward with swift and resistless energy. The secrets of the universe have been yielded up under the inquisitorial investigations of god-like intellect. The domain of the mind has been extended wider and wider. One planet after another has been added to our system; even the profound abyss which separates us from the fixed stars has been passed, and thousands of rolling suns have been descried, swiftly flying or majestically sweeping through the thronged regions of space. But the laws of Kepler bind them all; satellite and primary, planet and sun, sun and system—all with one accord proclaim, in silent majesty, the triumph of the hero philosopher!"

Let us consider for a moment the three laws of Kepler referred to in the preceding quotation for the purpose of simplifying them to the non-mathematical mind. In determining the curvature of an orbit, Kepler's attention was first directed to the circle, and he had there to determine whether, if orbits were circular, the sun as the centre of motion occupied the centre of the circle, or, if any, what other point within the circular area. The result of his first investigation was therefore merely negative. He definitively determined that orbits were not circular, and that the sun's position in the centre of a circular orbit, or at any other point within the area of a circle, would not account for the times and positions of the planet in its orbit, with reference to the sun. The next curve of the conic sections he investigated was that of the oval or ellipse, and here, after his long and patient examination, he at length found a curve which accounted for all the times and positions of the planets, with reference to the sun, and determined the position of the sun within the area of the orbit at the same time to be that of one of the foci of the ellipse. There are two well-known modes of producing the oval or elliptic curve, that of an oblique section of the cone, as already pointed out in a previous chapter, and the other the schoolboy method of a cord and two nails, or pins. By the section of the cone the positions of the two foci of the ellipse are not immediately apparent, but by the more common method of the cord and the pins the foci are at once determined as the points at which the two pins are fixed. Having determined his *first law, that all orbits are ellipses, with the sun or primary body in one of the foci of the ellipse*, it was almost a corollary, as we are now enabled to look upon the question in the light of later scientific discoveries, though by no means so relatively probable or apparent in Kepler's time, that his *second law* should be that *equal areas of their orbits are described by the planets in equal times*, though we fear the general reader will find this rather mathematical than popular language even still. Let us therefore make it more clear. It seems essential to a regular and well-balanced orbit, that it should not only be completed in equal times as regards each entire revolution of a body traversing it, but that where the restraining cause is focally situated, the various portions of the orbit should have some regular and relative balancing with reference to each other. Now it is found that the sun being in one of the foci of the orbitual ellipse, the planet is sometimes much nearer to the sun than at other times, and that the planet's nearest and furthest points from the sun differ to the extent of the entire distance between the two foci. When the planet is at its nearest point to the sun, it is moving with its greatest rapidity in its orbit; and when at its remotest point from the sun, it is proceeding at its slowest rate of speed in its orbit; but yet the orbit throughout its entire course is so balanced that the rapidity is exactly proportional to the nearness, and the slowness to the distance, in reference to each other, so that equal areas of the orbit are described by the planet in equal times. Let the diagram more particularly explain.



Here we will assume that the four lines passing from S, the focus of the orbit, in which the sun is situated, to the perimeter of the ellipse, at A B C and D respectively divide the *area* of the ellipse into four equal parts, though they obviously do not equally divide the *perimeter* of the ellipse. It follows from Kepler's second law, as an essential feature in the balancing of the orbit, that the planet will pass from B to C, the most remote period of its orbit, in precisely the same time it takes to pass from A to B, and will thereby describe the one-fourth of the area of its orbit, viz., the area A S B, in exactly the same time in which it describes any other fourth of the area of its orbit, such as B S C; but it does this only because it is travelling more rapidly from A to B than from B to C, and consequently is enabled by the difference of speed to accomplish the distance from A to B in exactly the same time as the distance from B to C; and were it not for this fact, *i.e.*, did it traverse the portion of its orbit from B to C without any diminution of the speed with which it arrives at B, then such a force continued beyond B would obviously throw the planet out of its orbit before it reached C; and in like manner, did its force diminish more rapidly than the rate at which it decreased along the extending distance from the focal position of the sun, in passing from A by B to C, the effect of any diminution of speed would be to contract the orbit, destroy its regularity and periodicity, and cause it to fall into the sun within a definable period. It must be obvious at once to the intelligent thinker, that so accurate a balancing of the orbits of the planets and planetoids cannot be a blind chance result of mere unconscious centrifugal force, as theorized by the supporters of Laplace's theory of the universe, or Olber's theory of the formation of the planetoids, but is the work of an intelligence accurate enough to perceive the exact measure of tangential force required at its mean distance from its primary to be given to the planet or planetoid to balance the orbit, and prevent its being unduly expanded from the weakness of the restraining heliocentric attraction, or unduly contracted from any preponderance in the power of that attraction; and that this intelligence so perceptive of the correct measure of these balancing forces involved in the quantity, and distance, and densities of the bodies balanced, must be also possessed of a sufficient power to place and arrange these mighty bodies in their relative positions, and set their great balancing forces in operation as counterpoises to each other. To suppose that these forces so justly measured to each other could be any result of blind nature, or a mere spontaneous operation of unintelligent matter, is as gratuitously absurd as to suppose a watch found in the desert, to use the illustration of Paley, to have been self-constructed because you do not find it stamped with the maker's name.

In giving the previous explanation of Kepler's law, we have, for the sake of the reader, availed ourselves of another law of which Kepler knew nothing, and in the absence of which and its important influence as a guide to his researches it is all the more remarkable that he should have made his wonderful discoveries; for, in speaking of the greater or less speed of the planet having the effect of destroying its orbit by undue expansion or contraction, we have been using the now well-known law of gravitation as an element of our explanation; but this law was not known to Kepler, nor discovered by Newton till long after Kepler was dead. Kepler's first and second laws were published in 1609, when his work on Mars appeared. Newton's great work, the *Principia*, was not published till 1687, seventy-eight years after Kepler's discovery, and till then the world knew nothing of gravitation as an astronomical law; yet it is difficult, viewing and reasoning on this subject from this age, to divest one's self of a suspicion that Kepler must have had some dim idea of an influence equivalent to gravitation being involved in this beautiful curve of revolutionary motion. Kepler's third law was not published till 1618, but that was still sixty-nine years before the announcement of the law of gravitation; so that Kepler, as the facts appear, worked out his great achievements in the dark altogether as to this important and guiding principle, by means of which alone we are enabled to render his labours intelligible to the general reader; for it is very clear that the law of gravitation is essential to the satisfactory explanation of his first and second laws, and that without it they are no more intelligible than Bode's law, already referred to, which has been now found to be a mere set of coincidences.

Let us next endeavour to explain Kepler's *third law: That the squares of the periodic times of the planets are proportional to the cubes of their major axes or of their mean distances;* for we fear that many who read the laws of Kepler see little more than mere coincidences in them even yet. As the expression of this law is in rather technical language to the general reader, we will be a little more definite, and suppose two planets, say Mercury and Mars, to be under investigation, though any two other planets will do quite as well. Then it will follow, from the application of the third law of Kepler, that if the square of Mercury's period in its orbit be taken and applied as an arithmetical divisor to the square of the period of Mars, the quotient or result will be the same figures as those which would be given by dividing the cubes of the mean distance, or the cubes of the major axes—that is, the cube of the mean distance, or of double the mean distance of Mars by the cube of the mean distance, or of double the mean distance of Mercury from the Sun; for it matters nothing whether the mean distance or double the mean distance be taken, provided, whichever of these be taken, the same be taken in both cases. But what does this law signify? It is this, that the space area or spherical area of attraction (we have used the term frequently at the outset of the present work) round the Sun, of which the mean distance of Mars from the Sun is the radius or semi-diameter, is just exactly as many times greater than the spherical space area round the Sun, of which the distance of Mercury from the Sun is the radius, as the square of the time that Mars takes to describe its orbitual revolution in its area is greater than the square of the time in which Mercury describes its orbitual revolution round the Sun. This is the usual explanation of this law, and appears to have been as far as Kepler was able to go into it, and its discovery has been very important; for, besides its application to all the planets and all the satellites, a recent application of it has given strong confirmation of the existence of the new planet Vulcan, in addition to the facts in regard to that planet we have already set forth. But yet the law, as so far stated, seems to be little else than a mere fact, universally true, no doubt, but not by any means intelligible, save by what Shakespeare calls a woman's reason, *it is because it is!* and if the reader be satisfied with an explanation in that state, we must confess, for our own part, we are not. But if the reader will favour us with his patience, we will now go a little deeper into the matter, and see if we cannot discover for him the cause of this law, and thereby throw a little broader light upon its value.

If for illustrating this law we take Mars and the Earth for our example, we find that the period of revolution of Mars is 687 days, and that of the Earth 365 days, and these periods when squared will give for the Earth 365 × 365 = 133,225, and for Mars, 687 × 687 = 471,769, and that the square of the period of Mars is therefore rather more than three times that of the Earth. In like manner if we take the mean distance of Mars, which is 142 millions of miles, and that of the Earth, which is 95 millions of miles, we have, in cubing these mean distances, 142 × 142 × 142 = 2,863,288 for Mars, and 95 × 95 × 95 = 857,375 for the Earth; and dividing these results by each other we shall find that the cube of the mean distance of Mars is rather more than three times the cube of the Earth's mean distance. This proportion between the squares of the times and the cubes of the mean distances is found so universally to prevail with regard to all the planets and satellites and other heavenly bodies known to move in orbits, that it has the evident force, not of a mere coincidence, but of an absolute law, without any exception.

Its importance is that it determines a distinct and uniform connection between the distance of every heavenly body from, and the period of its revolution round, its primary. It appears necessary to explain, however, that it is not necessary to multiply the periods by themselves, or take the squares of the periods, to obtain Kepler's result; for if the periods be multiplied by their halves or their fourths, or by any proportional of themselves, the same proportional being in every case taken, the same result will be produced. For example, if the period of two bodies be respectively 8 and 16, then the squares would be 8 × 8 = 64, and 16 × 16 = 256, and the latter result would be exactly four times the former; that is, 64 ÷ 256 = 4. But if these mean distances be multiplied by their halves or their fourths, they will still give the same result; for (by the halves) 8 × 4 = 32, and 16 × 8 = 128, and 32 ÷ 128 = 4; and so also (by the fourths) 8 × 2 = 16, and 16 × 4 = 64, and 16 ÷ 64 = 4. This fact has perhaps been a little too much overlooked in the ordinary statements of Kepler's third law; for it contains within it the exact secret which he first sought for in his investigation of it. Thus the side of a square is always *geometrically* the fourth part of the perimeter, and the diameter of a circle is always also a proportional, though never yet exactly determined, to the circumference of the circle; and so also is the major axis of an elliptical orbit to the length of the orbit. Now the law of Kepler involves this fact, that the period of a planet is a cycle of time, or the length of time required for the planet to make a complete revolution in its orbit; and that if this period of revolution were squared or divided into four equal parts, representing the four sides of a square, the period multiplied by one of these sides, which would of course be equal to the fourth of the period, would produce just such a proportional to the period of any other planet so treated, as the cube of the mean distance of the one planet would give to the cube of the mean distance of the other planet; so that, in fact, the squares of the times are in some sense cube quantities fundamentally, in this comparison, as well as the cubes of the mean distances; and the law, therefore, does appear to imply that the cubes of the times correspond with the cubes of the distances. It is not very easy to render this quite intelligible to the general reader, though it seems to involve a much wider comparison and coincidence than Kepler's law, as ordinarily stated, brings out, and opens up to us something of the rationale of the law; for it brings out this fact, that the square roots of the orbits, multiplied into their cubes, bear the same proportion to each other in the cases of all the planets and satellites as the (*geometrical*) square roots of the orbital period multiplied into their respective cubes &c. Hence it follows that the square roots, the squares, and the cubes of the orbits must all be proportionals, and the square roots, squares, and cubes of the periods be also all proportionals to each other in the degree in which square roots and their respective squares and cubes, geometrically considered, are proportionals to each other. Now it happens that the orbit is a bisection of the spherical (or rather elliptical) area of the attraction round the primary within which the planet's motion is regulated and controlled, and the period is a bisection of the spherical distribution of all the periods within which bodies of equal weights, distances, and velocities to those of the planets would be compelled to move round the primary, whatever might be the plane of their orbit; and the cause of the third law of Kepler hence appears to be, that bodies, of whatever weight and distance, moving round other bodies by the mutual attractions which retain them in an orbit, must have the spherical areas of their respective attractions proportional to the squares of their respective periodicities, or rather to the spheres of which their cyclical periods are great sections; in other words, to the times or periods it would take them to traverse the great circles of that spherical area in any possible great plane of it.

As so explained, the law involves the following laws in detail:—

1. The period of any planet or satellite in its orbit bears a definite relation to the area of attraction within which it moves round its primary, and this relation is the same in every planet and satellite.
2. This relation is, that the velocity of every planet or satellite in its orbit is so proportioned to the diameter of the orbit, that the area of attraction within which it moves has the same relation to the area of attraction within which any other planet or satellite moves, as the sphere of its cycle[*] has to the sphere of any other planet or satellite's cycle.
3. Hence all planets and satellites are balanced in their orbits on the same principle; their velocities, in whatever plane their orbits bisect the area of attraction within which they move, being proportioned to the dimensions of that area of attraction.

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[*] The expression is peculiar, and only capable of being made intelligible by specially explaining the sense in which we use it. A planet's period in its orbit is really a cycle or revolution or circle (ellipse), more strictly, of time, and the quantity of which this cycle would be a bisector is what is intended by the sphere of its cycle, and has the same relation to it as a sphere to its circular bisection. In such a

In fact, the orbits and the periods are not a coincidence, nor a blindly achieved accident, but a balance mathematically discriminated, and exactly poised,—an intelligent and perfect adjustment. That is the value, when penetrated to its root, of Kepler's great third law.

It will be observed that the primary coincidence occurs between the orbit and the cycle, between the ellipse and the period involved, and continuously repeated in describing it: and it was truly, though not at the time perceived by Kepler, in the cubes or spherical products of these quantities, comparing planets with planets, and satellites with satellites, that Kepler discovered the necessarily resultant mathematical coincidence expressed in his law. We might have given in arithmetical detail the preceding explanation applied to the whole planets and satellites of the solar system, had that been more likely to enlighten the general reader than our statement of the mathematical principles; but, unless the reader has the interest and perseverance to work out for himself the question of which we have given him the data, he would be little benefited by looking at columns of dry statistical and otherwise meaningless figures; and we gladly spare ourselves the labour of calculating or setting them forth, for we have little claim to the noble and heroic patience of that triumphant worker for truth, the great Kepler, who has made his own distinctive monument in science pre-eminently that of a beacon to the persevering.

With what a marked and satisfactory contrast does his great conclusion compare, on every ground of logical and scientific accuracy, with that of Laplace, in his explanation of the arrangements of the universe? Had the planets or satellites been projected in their orbits with a slightly greater or

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sense, both the circle of time and the sphere of time are positive numerical quantities, though we must confess to the helplessness of human language in so designating them.

slightly less degree of tangential force, or at a slightly greater or slightly less degree of distance from their respective primaries, or with a slightly different degree of direction at their first impulse, we have it on Kepler's authority, and reduced to mathematical demonstration, that in the course of a very few revolutions in their orbits the planets and satellites would all have either travelled outward away from their orbits altogether, or fallen into their several primaries, and finally into the sun. They therefore, as an inseparable corollary, must have been placed at their respective distances from their primaries, and projected in their orbits, by an INTELLIGENCE which perfectly perceived their relative gravitations, each to each, and by a co-operating POWER, mighty enough to calculate, apportion, and fix their varying distances, densities, and quantities to the minutest degree, so exactly that their arrangement can be nothing less than the work of ONE, *omnipotent* over them, who *hath literally measured their waters in the hollow of His hand—meted out their wide, heaven-spread spaces with a span—comprehended the dust of their earth in a measure—and weighed their mountains in scales, and their hills in a balance!*

Why is it the unconscious destiny of the reverential Kepler's great scientific antagonist, Laplace, in this explanation of the arrangement of the universe, to go to the forest, and cut the rod to lash himself with? Apply Laplace's calculation of the law of chances to these orbitual motions and periods in connection with his theory of them as resulting from self-generated centrifugal force. How many chances are there that a primary body, throwing out from it a portion of its own matter, under the influence of centrifugal force, generated as Laplace theorized, would throw it only far enough and with force enough to balance it in a permanent and recurring orbit round the primary, accurate in time and accurate in distance—compared with the chances that the projected matter would fall back upon the primary, or be projected beyond the influence and retaining power of its gravitation altogether? Why is it, if Laplace's theory of the universe have even a fragment of foundation in scientific fact, that there is not a single planet or satellite travelling under the influence of any one of these chances in the whole scope or range of known or explorable astronomy—not even taking the planetoids into account, with the theory of Olbers as to their formation endorsed as a highly plausible and popular fiction upon them? Surely, after such a fact, we may be pardoned for describing this centrifugal force theory of the universe, and of the origin of those orbitual motions with which it is apparently everywhere filled, as a baseless and credulous dream of mere materialism and positivism—a delusion, demonstrable even to absurdity, of the shallowness and gullibility of pantheistic faith!

Before leaving the subject it remains to be noticed that Newton found that an exception existed to Kepler's law where the mass of the planet has an appreciable ratio to that of the Sun. But this curiously enough only proves the law and the principle on which it is based; for whenever the mass of the planet has this appreciable ratio to that of the Sun, the centre of the Sun ceases to be in the focus of the orbit, but describes a small orbitual motion round the true focus, which is the real cause of the apparent exception. So that the orbit must then be calculated with reference to its true focus, and not to the centre of the Sun.

DIFFICULTIES IN ELEMENTARY MATHEMATICS.

CHAPTER XXXIII.

Elementary difficulties in Geometry—The duplication of the cube—The trisection of the angle—The quadrature of the circle—The difficulties investing these, and more especially the last of them—Some explanations.

THE achievements of astronomical science, though far short of the triumphs to which it is hoped they will yet attain, have been, as the reader will now perceive, of great and marked importance, and more especially in recent years; and when it is remembered that many of the elementary principles of geometry are still unknown, those outside the domain of practical or applied mathematics may well wonder by what marvellous skill and almost superhuman labour its triumphs have been accomplished, or such accuracy reached by the two distinguished mathematicians we have more than once referred to, who were able to predicate the position of the new planet Neptune before it could be said on any other ground of certainty to exist.

About a hundred years ago (1775) the Academy of Sciences of Paris, and soon after that time the Royal Society in this country, abandoned all attempts at the discovery of the quadrature of the circle, or the determination of its square contents, as hopeless; and, for the purpose of discouraging what they declared to be futile attempts at the solution of that question, and also of some others, publicly announced that they would not in future examine any paper pretending to give the quadrature of the circle, the trisection of an angle, the duplication of the cube, or the discovery of the perpetual motion.

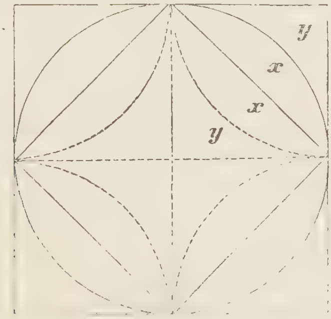
Leaving consideration of the perpetual motion out of the question, the difficulties investing the other three problems, which are purely mathematical, were found to be so great, and so many vain and really futile attempts had been made to solve them, that the consideration of the pretensions to their solution was found to be only a waste of time. The duplication of the cube had been solved by Hippocrates, of Chios, but not by means of elementary geometry. The trisection of an angle has also been accomplished by means of the conic sections and other curves, but never by plane geometry; but the quadrature of the circle has never been accomplished by any means, direct or indirect; and, indeed, it has been demonstrated (?) that its solution is impossible. Unlike the other two, this third problem is evidently a question of plane geometry, if it be capable of solution at all; but hitherto only approximations to it have been made. These approximations have been the results of immense labour. Van Ceulen, assuming the diameter to be one, carried the approximation of the circumference as a means of reaching the square contents or quadrature of the area to thirty-six figures, namely, 3·14159, 26535, 89793, 23846, 26433, 83279, 50288. Mr. Abraham Sharp carried it to ninety-two places of figures, De Lagny to one hundred and twenty-eight, and Dr. Clausen to two hundred and fifty places. The interest in the question, and the labour expended upon it, will thus be seen to have been very great.

Fortunately, as we have seen, orbitual motions are not performed in circles, but in other conic sections, which are more easily dealt with; yet, for many practical purposes, an easy mode of finding the exact square contents of the circle is sufficiently desirable to provoke numerous aspirants still to attempt its solution, notwithstanding the declaration of its impossibility and the many failures which have been incurred for the last three thousand years in the attempt.

We are not aware that the following mode of approaching the question has hitherto been tried, and in showing the difficulty of the subject we will, we are sure, be pardoned for submitting it to the attention of the general reader, especially as it places the question in an intelligible as well as in a somewhat novel light. Of course we are not presuming to knock at the closed doors of the Academy of Sciences of Paris, nor at those of the Royal Society of our own country.

It will be seen from the following diagram (fig. I.), which

Fig. I.



consists of a circle inscribed between two squares—a square interior to, but in contact at its four angles with, the circumference of the circle, and a square exterior to, but in contact at the centre of each of its four sides, with the circumference of the circle—that all squares and circles having the same relative proportions to each other as those of the diagram, are exactly and exhaustively divisible by two quantities of fixed but unknown dimensions, which we have respectively marked x and y.

The interior square consists of exactly $4x + 4y$ quantities, the circle of exactly $8x + 4y$ quantities, and the exterior square of exactly $8x + 8y$ quantities. It follows from thence that the exterior square contains exactly twice the square contents of the interior square; for whatever the contents of x or of y may be, the exterior square contains just twice as many of both of these quantities as the interior square; but in consequence of the exact contents of x as compared with y not being known, we cannot tell the square contents of the interposed or interscribed circle, which consists of unequal quantities of x and y,—viz., eight of the one, and four of the other; and, unless we can discover the exact square contents of x and y, or both, we cannot discover the square contents of the circle. There is no mode of determining this directly; for x and y are not rectilineal quantities, but consist of portions or areas of space, bounded partly by straight lines, and partially by lines of circular curvature. But then the question suggests itself, Are there no indirect means of determining exactly the quantities x and y? To enable those who care to go far enough into the question to satisfy themselves on this subject, let us place before them the following further diagrams.

Fig. II. consists of three concentric circles of different sizes one within another. The second circle is four times greater than the first, or inner circle; and the third, or exterior circle, is four times greater than the second, and consequently sixteen times greater than the first. And it follows from this that the quantity, or space (segment of the circle), contained between the chord and the arc A B, and the fourth of the circumference, and marked as the quantity x in the first or smaller circle of the diagram, is one-fourth part of the segment (quantity or space) intercepted between the chord and arc of the second circle D E, and is one-sixteenth of the segment intercepted between the chord and arc of the third or largest circle F G. This is easily demonstrable by the fact that the triangle A B C forms, and is equal to, one-fourth of the triangle C D E, and to one-sixteenth of the triangle C F G. Hence the segment intercepted between the chord and arc A B$=x$, the segment between the chord and arc D E$=4x$, and the segment between the chord and arc F G$=16x$, as marked in the diagram; because, by demonstration, the quantity x has the same proportion to the triangle A B C, as the quantity $4x$ has to the triangle C D E, and as the quantity $16x$ has to the triangle C F G. This being obviously capable of the most rigorous and complete geometrical demonstration, which we omit giving merely to avoid tediousness, let us now turn our attention to the following additional diagram, fig. III.

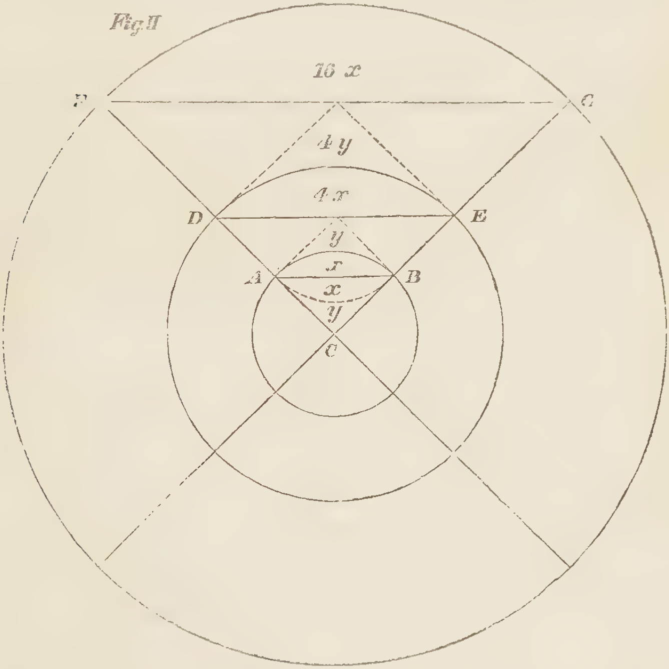
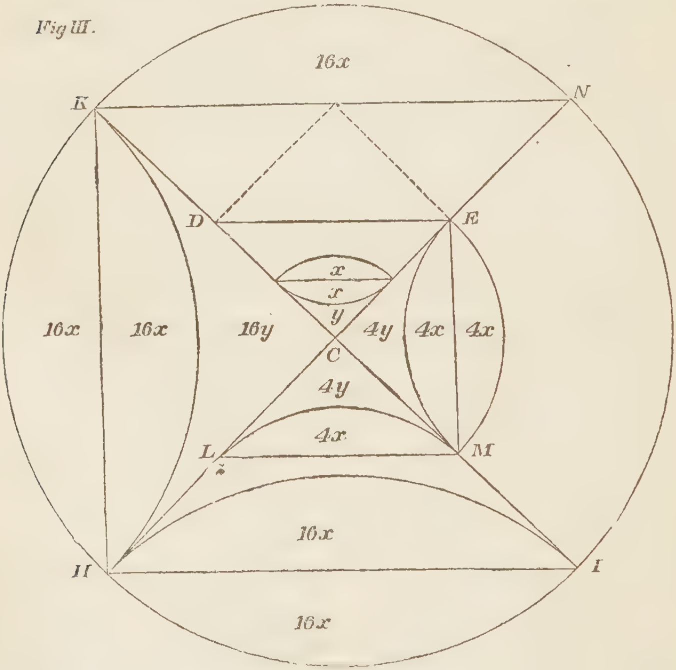


Fig. II

In the following diagram it will be observed that the three circles of the previous diagram are partially reproduced, and that we have the x and y quantities of both, so that the triangle C H K contains $16\,x$ and $16\,y$ quantities. But it will also be observed that the triangle C H I, is equal to the triangle C H K, and therefore $= 16\,x + 16\,y$, and that this

Fig III.



triangle is, as shown in the diagram, capable also of being subdivided into four quantities, a $16\,x$ quantity, a z quantity, a $4\,x$ quantity, and a $4\,y$ quantity, so that the triangle C H I $= 16\,x + 16\,y = 20\,x + z + 4\,y$; and it will appear, by comparing $z + 4\,x + 4\,y$ in the triangle C H I with the $16\,y$ quantity of the triangle C H K, that $z + 4\,x + 4\,y = 16\,y$, and that consequently $z + 4x = 12y$. Our object, therefore, if we would attain to the square contents of the circle in this direction, is to ascertain the relative dimensions of the three unknown quantities x, y, z. To accomplish this it will be found, on looking at the diagram again, that the triangle $\text{CLM} + z = 16y$, and the quadrilateral (*rectilineal*) area $\text{HILM} - z = 16x$. But HILM is equal to three times the triangle CLM, as may be seen by looking at the similar quantity DEKN at the upper part of the diagram, where $\text{DEKN} = \text{HILM}$, and $\text{DEKN} =$ three times CDE, and $\text{CDE} = \text{CLM}$.

If then $\text{CLM} = s$ as a corollary, $\text{HILM} = 3s$; and by reference to the diagram, and what has been already stated, we have the following elements:—

$$\left.\begin{array}{l}\text{CLM} = s\\ \text{HILM} = 3s\end{array}\right\}\text{ whence as already shown }\left\{\begin{array}{l}s + z = 16y\\ 3s - z = 16x\end{array}\right.$$

$$\begin{array}{ll}\text{But if from} & 3s - z = 16x\\ \text{we deduct} & \underline{\;\;s + z = 16y}\\ \text{we have} & \underline{\underline{2s - 2z = 16x - 16y}}\end{array}$$

And if $2s - 2z = 16x - 16y$, then $2s + 2z = 16x + 16y$; but, by the diagram, it is apparent that $s + z = 16y$, so that if $2s + 2z = 16x + 16y$, then also $2s + 2z = 32y$, consequently $16x + 16y = 32y$, and $16x = 16y$, and $x = y$, and $z = 8x = 8y$.

This singular equation, which we can further geometrically demonstrate, but which involves too many important geometrical consequences to be further gone into, except in a special treatise on geometry, furnishes the following remarkably simple rule for finding the area of the circle. Every circle is divisible (recurring to fig. I., p. 395) into x and y quantities, and contains, when so subdivided, $8x + 4y$ quantities; but the circumscribing square of such a circle, which is equal to the square of the circle's diameter, contains $8x + 8y$ quantities; or, x being equal to y, the circumscribing square contains one-fourth more space than the circle inscribed within it: whence, *multiply the diameter of the circle by itself, and deduct one-fourth of the amount, the remaining quantity is the area of the circle.*

But the test and proof of this solution is at immediate command by another process; for if $z = 8x = 8y$ and $x = y$, it is a corollary that twice the circle must be equal to three times the inscribed square; for, as appears from Fig. I. (p. 395), if $x = y$, there are eight times this equal quantity in the inscribed square, and twelve times the same quantity in the circle there delineated; whence 8 × 3 times the inscribed square = 24 and 12 × 2 of the circle = 24. That three times the inscribed square is demonstrably equal to twice the circle, will appear as follows:—

By reference to Fig. III. it will be seen that the large circle there fully delinineated contains $128x + 64y$ quantities, because the fourth part of it, intercepted by its two radii at H and K, contains $32x + 16y$ quantities. Hence twice that circle $= 256x + 128y$. And it will also be seen, by reference to the same diagram, that the square inscribed in the large circle, and of which the right lines H I, H K, H N, form three of the sides, must contain $64x + 64y$ quantities, because the fourth of it included in the triangle C H K $= 16x + 16y$. Hence three times that inscribed square $= 192x + 192y$. But the inscribed square contains also, or may be subdivided into, $16s$ quantities, as will be seen from the diagram (s being equal, as before mentioned, to the triangle CLM, which contains $4x + 4y$ quantities); because the triangle C K N $= 4s$, which is also equal to one-fourth of the inscribed square. Whence, the inscribed square being $= 16s$, three times the inscribed square $= 48s$. But $48s = 256x + 16z$; because, as will be seen by the rectilineal area H I L M, which, as we have already shown, contains three times the s quantity, $3s = 16x + z$, and consequently $48s = 256x + 16z$.

We have thus two equations of the inscribed square, from which it is demonstrable that—

Three times the inscribed square $= 256x + 16z = 192x + 192y$.

Let us now deduct these ascertained equations of three times the inscribed square and twice the circle from each other, to ascertain the difference, if any, between them, as follows:—

$$\begin{array}{ll}
\text{Twice the circle} & = 256x + 128y \\
\text{Thrice the inscribed square} & = 192x + 192y \\
\hline
\qquad \text{Difference} & \quad\; 64x - \;\, 64y \\
\hline\hline
\end{array}$$

And with the other equation of the inscribed square:—

$$\begin{array}{ll}
\text{Thrice the inscribed square} & = 256x + \;\; 16z \\
\text{Twice the circle (as before)} & = 256x + 128y \\
\hline
\qquad \text{Difference} & \qquad\qquad 16z - 128y \\
\hline\hline
\end{array}$$

To show that these differences mean $= 0$, it is only necessary to add them together, as follows:—

$$\begin{array}{c}
64x - \;\, 64y \\
16z - 128y \\
\hline
(16z + 64x) - 192y = 0
\end{array}$$

For, as appears from the diagram, $z + 4x = 12y$, and, as a consequence, $16z + 64x = 192y$. So that:

$$(16z + 64x) - 192y = 192y - 192y = 0.$$

It is thus demonstrable that the area of the circle is equal to three-fourths of the square of its diameter, or of the area of the circumscribed square, and that, concurrently, twice the circle is equal to three times the inscribed square; and thus this beautifully subtle and complex problem yields itself up so far at last to demonstration.

Of course these facts afford very obvious new data for estimating the ratio between the area, the diameter, and the circumference of the circle. But, as already intimated, we must reserve this entire subject, as well as that of spectrum analysis, for further and separate treatment, and claim the privilege of respectfully and gratefully bidding our readers, for the present, adieu!

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